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# Visual Flow Analysis

By C. C. PERRY. (From *Product Engineering, U.S.A.*, Vol. 26, No. 8, August 1955, pp. 154-161, 19 illustrations.)

THERE are many situations in the design of fluid-dynamic devices in which the flow conditions are too complex for mathematical treatment. If a theoretical expression for the flow pattern is obtained at all, it may embody so many approximations and assumptions that there is little resemblance between theoretical and actual conditions. Point-by-point instrumentation of the flow pattern is often impractical, if not impossible. These considerations, in addition to the desire for a picture of the overall character of flow, have resulted in the evolution of a number of techniques for making flow patterns visible. With these visual techniques it is possible to determine whether the flow is laminar or turbulent, whether separation and eddying are present, and whether there are secondary flows to be eliminated. Permanent records can be obtained with photographs or sketches.

Because of the differences in density, viscosity, and compressibility between liquids and gases, the two types of fluids are here treated separately. It should be borne in mind that at subsonic velocities the flow of any gas is directly comparable with that of a liquid at the same Reynolds number. It may be more convenient or practical to conduct visual studies with a different medium than that employed in the device being investigated. The only limitation to this practice is the necessity for maintaining complete dynamic similitude.

## LIQUIDS

Although the following discussion emphasizes water, since this is the most common working medium, the methods described are suitable for most liquids.

### ADDITION OF CONTAMINANTS

The liquid and the nature of its enclosure determine the particular contaminant to be used. For fully enclosed flow it is customary to build a transparent model of the prototype for viewing the flow. If the flow is laminar, streamers of dye, such as potassium permanganate or ink, will trace path lines. Turbulent flow is much more common and requires granular, flaky, or globular contaminants, such as aluminium powder, small chips of mica or micaceous iron ore, small plastic or glass beads, rubber or cork particles, air bubbles, or globules of a liquid immiscible with the primary liquid. When photographed with a flash bulb, the contaminant particles produce well-delineated flow patterns. High-speed motion pictures may reveal details such as small eddies, reverse flow at separation points, and local regions of instability.

The specific gravity of the contaminant should be nearly the same as that of the primary liquid. This restriction becomes less critical as particle size is reduced, since surface forces are then much larger than gravity or inertia forces. Carbon tetrachloride and benzene can be mixed in proportion to produce a specific gravity equal to that of water, as can mixtures of nitrobenzene and olive oil, wax and rosin, and xylene and carbon tetrachloride. These fluids will tend to form discrete globules in water which can be observed because of their differing index of refraction. Air bubbles are a convenient form of additive because of the ease with which their concentration can be controlled. There is also no risk of damaging rotating parts, bearings, or small clearance surfaces.

For flow which can be simulated with a two-dimensional system a model can be placed in an open channel and the surface of the flowing liquid sprinkled with powder, such as lycopodium, sawdust, or aluminium, to reveal the character of motion. Photographs of the liquid surface will record the motions of the particles as streaks which are the fluid-path lines past the model, as shown in Fig. 1. The flow velocity in an open channel must ordinarily be limited to less than one foot per second, to avoid creating waves on the free surface. This limits the maximum Reynolds number attainable in such a system. An improvement is possible by the use of a liquid with a lower kinematic viscosity than water.

### WEATHERCOCKS

Miniature weathercocks or freely swinging vanes can be highly practical indicators of flow direction. Tufts of wool or silk, tied to the model or to a wire grid in the vicinity of the model, have also been used very successfully. Vanes and streamers will take positions corresponding to zero turning moment, and will point downstream. This technique is simple and inexpensive, requiring no instruments except a camera to make permanent records.

### STREAMING DOUBLE REFRACTION

When water containing the correct type and size of suspended matter is caused to flow through a transparent channel and subjected to a beam of polarized light transversely to the direction of flow, a pattern of coloured bands, or isochromatics, appears. The

Fig. 1. **The Karman vortex-trail downstream from a cylinder, indicated by the paths of floating particles in an open channel. (Ann Arbor Instrument Works)**

Fig. 2. **Study of flow around an aerofoil at various angles of attack, using smoke streamers for visualization. (National Advisory Committee for Aeronautics)**

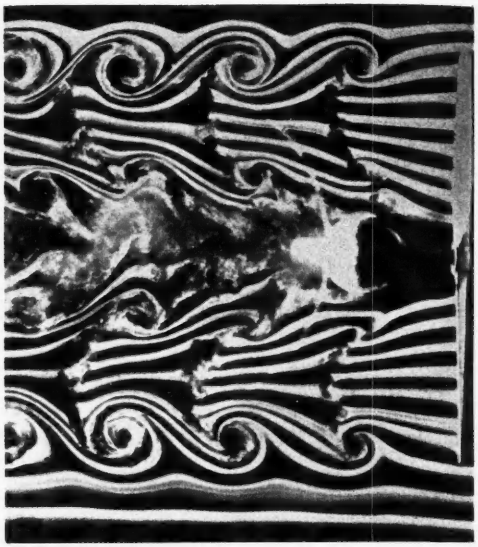

Fig. 3. **High-speed flash photograph of flow past a propeller, with smoke filaments in the air stream. (Prof. F. N. M. Brown, University of Notre Dame)**

optical principles employed here are the same as in photoelastic stress analysis. The colours of the bands are related to the rate of shearing strain in the water. With laminar flow, quantitative data on shearing strain rate, and thus velocity gradients, can be obtained ; when, however, the flow is turbulent, this technique gives little more than qualitative information.

A number of materials can be employed as the double refracting agent. Bentonite clay, when of the correct degree of fineness, will disperse itself in the water as tiny platelets which, under the action of shearing strains, apparently take an orientation producing the desired optical effect. Vanadium pentoxide particles produce similar results. Dilute solutions of a special synthetic dye have also been used with marked success.

### Boundary Flow

The flow of the boundary layer is often an excellent index to the general mode of flow through or around a fluid-dynamic device. With the exercise of a little ingenuity it may be possible to cause the boundary layer to record its own actions.

One technique employed in studying the characteristics of model boat hulls uses a model painted with a "dead-flat" white-lead paint. At the leading edges of the areas on the model where streamlines are to be recorded, a series of small holes is made for the purpose of introducing hydrogen sulphide during the test. When the proper hydrodynamic operating conditions have been established, a concentrated solution of hydrogen sulphide in water is fed slowly through the holes, and, as it is carried with the boundary-layer water, it combines with the lead in the paint to form lead sulphide, leaving distinct black streaks on the white surface of the model.

Another technique is to paint the boundary surface of the model with a thick layer of paint (any colour) and to test before the paint dries. The boundary layer flow will erode lines in the fresh paint, indicating the local flow directions. This method is most suitable for small models which can be quickly painted and tested, but does not lend itself to photographic recording of the traces. A similar technique involves the use of streaks of paint applied transversely to the general direction of the flow and tested while the paint is still wet. Some of the paint will be dragged downstream to produce a rough picture of velocity and direction.

If it is convenient to fabricate the model, or at least the surfaces which form the liquid boundaries, from soap, ice, or some similar substance, warm water will erode a pattern from which certain characteristics of the flow can be inferred.

## GASES

Since air is the most common and important gas, the following discussion is restricted to air, although the principles described are generally applicable to all gases.

### Addition of Contaminants

Smoke and visible vapours are most frequently used as subsonic air-flow contaminants. The usual practice is to introduce smoke or vapour into the air stream through one or more small nozzles, forming individual filaments which flow through or around the model being studied. The resulting traces represent fluid-path lines. Smoke or vapour trails also serve to demonstrate the presence and severity of separation, vorticity, or turbulence. Figs. 2 and 3 show typical visualizations obtainable with smoke streamers.

The contaminants used include kerosene vapour, smoke from burning wheat straw or oil-soaked cigars, and chemically produced smokes. The use of smoke streamers limits the range of air velocities which can be studied. At low velocity the smoke filament will be affected by gravity and will deviate from the true path line if its density is different from that of air. As velocity increases, the distance over which a continuous filament of smoke can be maintained is reduced.

For very high air velocities and turbulent flow it is more effective to employ contaminants composed of discrete particles. The particles show up in flow photographs as streaks representing flow paths. Balsa dust has been used for this purpose because of its comparatively low mass and high reflectivity. Other solid-particle contaminants used with air include small tufts of wool, bits of paper, soap bubbles, chalk dust, and even glowing coals. The principal limitation to many of these contaminants is the damage inflicted upon the aerodynamic model or the wind tunnel.

### Weathercocks

Direction indicators may take the form of small pennants or streamers of silk or wool attached to miniature flag poles mounted on the model. Each streamer assumes an orientation corresponding to zero turning moment and points downstream to indicate the direction of flow in its vicinity.

Indicators can also be fabricated from thin sheet metal and hinge-mounted on pins so that they swing freely. The vanes must be mounted to swing in the horizontal plane, unless aerodynamic forces are much greater than gravity forces.

In another system a number of woollen tufts is mounted on a screen downstream from the model (in a wind tunnel), and the tuft deflection is photographed from a point still further downstream. The result is a well-defined cross-sectional picture of the flow in the wake of the model.

### Methods Based on Density Changes

Three different systems of air-flow visualization based on density variations in the air are employed.

The simplest method, called the shadowgraph technique, is shown schematically in Fig. 4. If a brilliant point-source of light, e.g., an electric spark, is so located that its rays pass through the air flowing in the vicinity of the model, a film on the opposite side of the air stream will record any density variations occurring in the flow around the model, by producing areas of varying contrast on the film as a result of corresponding variations in light refraction. Under normal subsonic conditions only minor changes in density will occur, with relatively little contrast on the film ; with transonic and supersonic flows, and the accompanying compressibility effects, sharp flow pictures can be obtained.

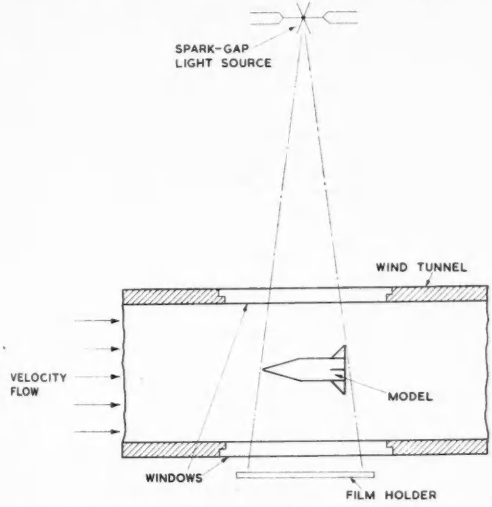


Fig. 4. **Schematic diagram of the shadowgraph technique.**

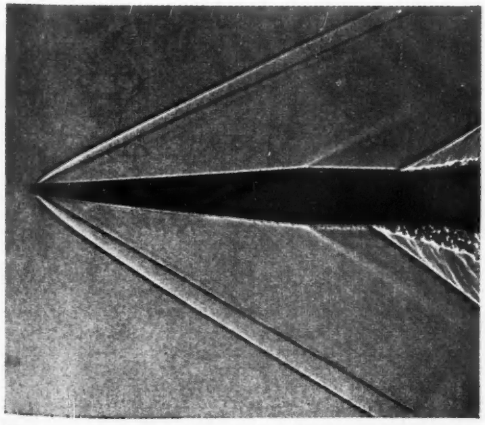

Fig. 5. **Shadowgraph of a missile in free flight at 1500 mph. (National Advisory Committee for Aeronautics)**

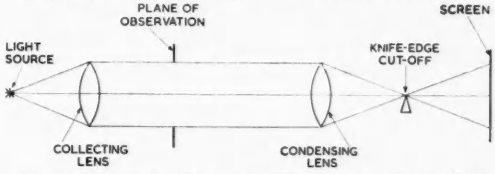


Fig. 6. **Schematic diagram of basic components of the Schlieren system.**

Because of its low cost and freedom from optical complexity, this system is quite widely used for aerodynamic research, though little quantitative data can be obtained from it. Fig. 5 is a typical shadowgraph obtained with this technique of a missile in free flight at 1500 mph.

The second method is the Schlieren system. Like the shadowgraph, a light beam traverses the air stream and similarly depends upon changes of index of refraction with density to cause visible flow patterns. Fig. 6 illustrates the basic components of the Schlieren system, i.e., a light source, a lens for creating a parallel beam of light, a second lens for converging the beam to a point, a knife-edge for obtaining and controlling optical sensitivity, and a screen for observation or photography.

In practice the knife-edge is first adjusted (with no air flow) so as to cut off part of the light beam until the field image on the screen is uniformly dark but not completely devoid of light. With the introduction of air flow, any density variations in the vicinity of the model cause refraction or bending of the light rays. Those rays which are bent upwards miss the knife-edge entirely and cause correspondingly brightened areas on the screen, while the rays bent downwards are intercepted by the knife-edge and produce darker areas on the lower half of the screen. Fig. 7 shows a typical Schlieren photograph of a missile at a supersonic speed. In this photograph it will be noted that the dark and light areas above and below the missile are reversed.

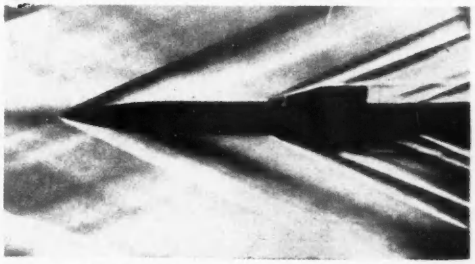

Fig. 7. **Schlieren photograph of a missile at Mach number 2·8. (National Advisory Committee for Aeronautics)**

The Schlieren system is very sensitive, even to low-density gradients. Although the shadowgraph and Schlieren systems are used most commonly for transonic and supersonic flow investigations, they can be adapted to subsonic testing by the introduction of synthetic density gradients. If heated wires are placed in the wind tunnel, upstream from the model, they will shed

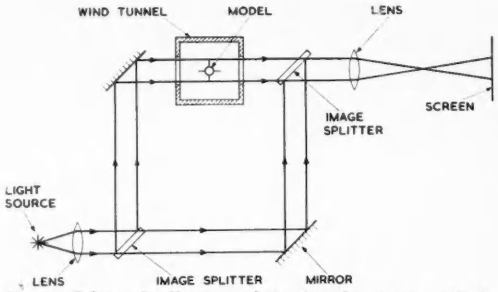


Fig. 8. **Schematic diagram of the interferometer optical system.**

streamers of warm (and less dense) air. A shadowgraph or Schlieren system will show the trace of these warm air filaments as they flow past the model.

The third method is the interferometer system. This technique employs the most complex optical arrangement but is capable of producing quantitative data on the density at any point in the field being studied. The interferometer system is composed, as shown in Fig. 8, of a light source, a collimating lens, two light-beam splitters, additional mirrors and lenses, and a screen. The first splitter divides the light, sending half of it through the wind tunnel and half by a roundabout path. The light beams are re-united by the second splitter and focused on the screen for observation or photography.

Density variations in the air around the model retard or advance the light rays passing through that area, while the control beam is unaffected. When the two beams are reunited, interference fringes are formed, as shown in Fig. 9. By noting the degree of shift in the fringes under different flow conditions it is possible to determine the air density at each point and, through aerodynamic and thermodynamic relationships, other significant variables for proper interpretation of the flow conditions.

Each of the three optical systems is sensitive to a different function of the density. The interferometer system senses the density variations themselves, the Schlieren system responds to density gradients, and the shadowgraph technique detects the rate of change of density gradient. These functional differences will sometimes affect the choice of visualization system for a particular aerodynamic study.

### Boundary-Marking Techniques

When it is impractical or inexpedient to construct a transparent model for flow visualization, a record of the boundary-layer flow can ordinarily be used to produce an acceptable picture of the overall flow pattern.

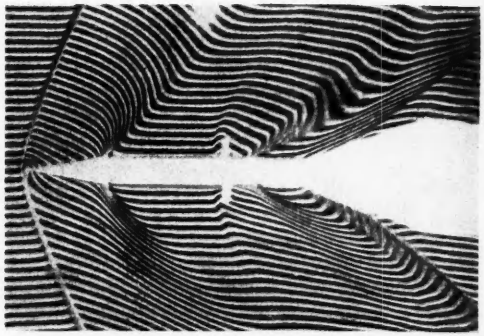

Fig. 9. **Interferogram of air flow past a missile at Mach number 1·39, illustrating interference fringes. (Dr. H. W. Liepmann, California Institute of Technology)**

In one method a mixture of kerosene and lampblack is applied to all surfaces of interest on the model, which is immediately subjected to the prescribed test conditions. The wet mixture tends to flow along the surface in the direction of the boundary-layer flow and, as the kerosene evaporates, the patterns become fixed for observation after disassembly of the unit. Some investigators have introduced the kerosene-lampblack mixture into the air stream just ahead of the test unit during operation. The mixture deposits on most of the boundary surfaces and, as above, becomes fixed to form a relatively permanent pattern.

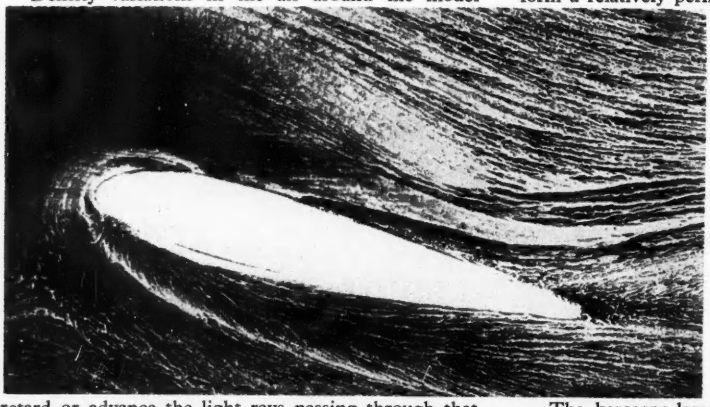

Fig. 10. **Flow around an aerofoil, as recorded by a kerosene and lampblack mixture on a glass plate used as the end boundary for the wing. (David Taylor Model Basin, U.S. Navy Dept.)**

The kerosene-lampblack technique is inexpensive simple, and versatile, and has been used to study the inlet and outlet flow patterns of compressors, fans, cascades, and other blade systems. The same technique has also been applied to external flows (around an aerofoil, for example, as shown in Fig. 10).

In another technique the boundaries are coated with a thick layer of paint and the device tested before the paint dries. The air flow past the boundaries will erode and drag out a pattern indicating flow directions.

There are also techniques used primarily for indicating the transition of the boundary layer from laminar to turbulent flow. Thin coats of volatile indicating liquids are applied to the model surface immediately prior to testing. Since the rate of evaporation is much greater in the region of the turbulent boundary layer than in the laminar, the test can be stopped before the coating has completely dried and the model examined for wet and dry zones. The contrast between the wet and dry regions can be heightened by employing coatings which have different optical properties in the two conditions, or by sprinkling a reflective powder over the model, so that it will adhere to the wet areas.

# A Technique for Machining Tungsten

By R. LEVI. (From *Philips Technical Review*, Vol. 17, No. 3, September 1955, pp. 97-100, 3 illustrations.)

*Pure tungsten metal obtained by the well-known sintering process is extremely hard and brittle at normal temperatures, so that machining possibilities are very limited. The technique for machining tungsten described in the following, although primarily developed for the manufacture of "dispenser"-type cathodes, may well prove valuable for other applications of tungsten metal.*

APART from the highly developed and mechanized technique of drawing tungsten wire, machining possibilities for the very hard sintered tungsten ingots at normal temperatures are restricted to grinding and slicing by means of silicon carbide cut-off wheels. Such a procedure can obviously be useful only for simple parts of convenient dimensions. Attempts to form the parts before the final sintering operation, either by pressing the tungsten powder in a die or by machining pre-sintered bars (density about 55%) have not been very successful. Machining of the very porous pre-sintered bars does not yield smooth surfaces, since the particles are torn out in clusters rather than cut. Moreover, considerable shrinkage and warping generally occur during the final sintering process, making it very difficult to obtain the required shape and dimensions.

The technique described here was specially developed for applications of tungsten in which a certain accurately controlled porosity of the metal is an essential condition. Basically, it consists of the following steps :—A porous ingot of tungsten, already sintered to the required degree, is first infiltrated with a suitable molten metal which does not react with the tungsten in any way. The impregnated tungsten body can then be machined at normal temperatures with conventional tools. Finally, the infiltrant is removed by volatilization, and an accurately machined pure-tungsten part is thus obtained, with its porosity restored to the exact value established during the sintering operation.

Fig. 1 illustrates the appearance of a tungsten part in various stages of the process. Copper was used as the infiltrant in this case. Owing to subsequent oxidation of the copper at the surface, the machined part will exhibit only a slight difference in colour before and after volatilization ; these two stages are therefore not shown separately in the photograph.

It should be pointed out that the infiltration of porous tungsten bodies with metals such as copper or silver has been known for many years and has been used for making spot-welding electrodes and certain types of electrical relay contacts. Such contacts must primarily possess good electrical conductivity, the copper or silver contributing to this end, while the role of the tungsten is to prevent contacts from sticking or being welded together by arcing. The purpose of infiltration in the machining technique described here is quite different. This is seen most clearly in the selection of the infiltrating metal. In both cases the molten infiltrant must wet the tungsten and penetrate the porous body by capillary action. For the machining technique, however, an additional requirement must be satisfied, i.e., the infiltrant and tungsten must be mutually insoluble below as well as above the melting point of the infiltrant. Moreover, the infiltrant should not only act as a "filler" but also as a lubricant during the machining operation, this combined action preventing the tearing out of particles, as well as the burnishing and high tool wear which would otherwise occur.

Gold, copper, and their alloys in all proportions appear to conform best to the above requirements. The cost factor should not prevent the use of gold, since the latter, when removed by volatilization, can be recovered. Silver, on the other hand, is not a very

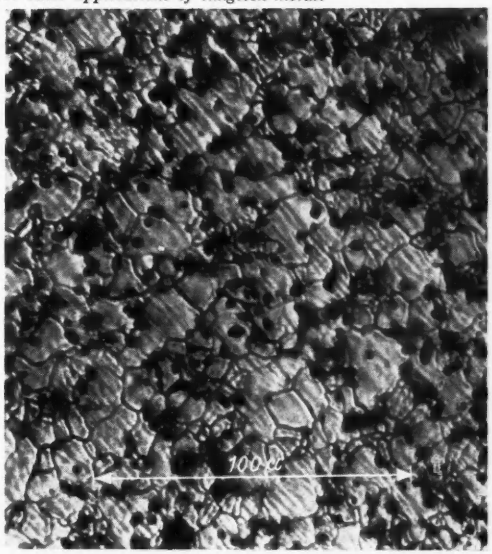


Fig. 2. **Photomicrograph showing a polished section of the tungsten surface after volatilization of copper.** The average pore size is of the order of a few microns, the pore separation varying between a few microns and a few tens of microns.

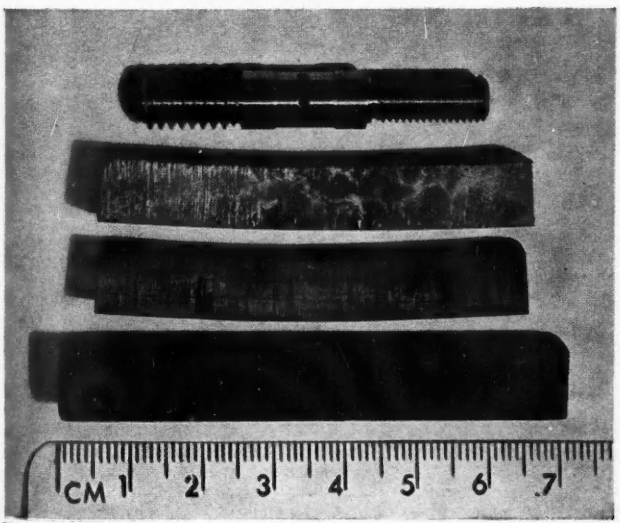


Fig. 1. **Steps in machining a tungsten part, according to the new method.** From bottom to top : Pre-sintered tungsten bar (density 55% of the value for solid tungsten) ; tungsten bar sintered to the required density (83%) ; sintered tungsten bar after impregnation with copper ; part machined by normal operations from the impregnated bar.

satisfactory infiltrating material, since tungsten shows a slight solubility in molten silver. The reprecipitation of tungsten onto the larger grains, which takes place upon cooling, changes somewhat the value and character of the porosity attained during the initial sintering operation.

When using copper, the impregnation is carried out at about 1350° C for a period of not less than 10 minutes in the case of ⅜ in. × ⅜ in. ingots ; larger ingots require a longer impregnating time. It is important to infiltrate the ingot completely ; otherwise, breakage of the tungsten or of the tool may result. Infiltration is carried out in a hydrogen atmosphere, with the ingot placed on top of a weighed amount of copper. At first the temperature is slowly raised to a point below the melting point of the impregnant and held there a few minutes to permit the interior of the ingot to attain the same temperature as the surface. When the temperature is finally raised to 1350° C, the molten copper will penetrate the tungsten body from the bottom by capillary action, this process being facilitated by the fluxing action of the hydrogen.

No tungsten grains can be detected by microscopic examination of a freshly machined surface, since a thin copper film has been smeared over the entire area. If the copper film is chemically removed, the smoothness and flatness of the grains indicate that they have actually been cut by the tool and not merely torn out.

The volatilization of the copper is effected by heating the machined parts in a vacuum furnace at 1800-1900° C. The resulting parts show only an extremely faint trace of copper. To retain dimensional stability and proper porosity of the machined parts during the volatilization (Fig. 2), it is essential that sintering of the tungsten frame prior to the infiltration be carried out for a sufficient length of time, at a temperature considerably higher than that necessary for the subsequent evaporation of the copper. Since the proper sintering temperature depends to a large extent on the characteristics of the tungsten powder, on the pressure used in forming the bars, and on the sintering atmosphere (e.g., its water-vapour content), all these factors have to be carefully selected.

Normal machining operations on the infiltrated ingots can be carried out with relative ease at densities as high as 83 to 84%. Increases in density above this value will make machining progressively more difficult because of a rapid increase in the percentage of non-connecting pores which cannot be infiltrated. This limits the application of the technique described to tungsten parts with a density slightly less than 90%.

U.S.A.

# A Fully Integrated Shell-Moulding System

A NEW and fully integrated shell-moulding system which includes all process equipment from sand preparation to handling of finished castings has recently been developed by the Link-Belt Company, of Chicago, Illinois, and it is claimed that, with only two men operating the shell-moulding and closing machines, 240 moulds per hour can be produced. These moulds can be easily transferred to the pouring conveyor or stored indefinitely until needed. Furthermore, the use of smaller gates and risers, smaller allowances for machining, and thinner sections, made possible by this process, is stated to result in a higher yield of usable castings, smaller amounts of metal melted, and a reduction in melting capacity.

The shell-moulding, core-setting, and shell-closing operations can be performed by fewer and less-skilled workers than in the preparation of green sand moulds. These operations are virtually dust-free and permit a substantially cleaner foundry. Shells are prepared on a four-station shell-moulding machine. The first station (Fig. 1) forms a shell by dropping or " investing " on a heated metal pattern a measured volume of mix, consisting of thermosetting resin and sand. A flask confines the sand and resin over the pattern, while water-cooling prevents build-up on the inside surface of the flask. Excess sand mix is removed by a roll-over motion, the flask is withdrawn, and the pattern with its soft plastic shell covering moves to two successive curing stations (Fig. 2), equipped with infra-red heaters, where the desired hardness is obtained. The thin shell is removed by the operator at the ejector station (Fig. 3). The pattern is then sprayed with a release agent to facilitate shell removal and again passes to the investment station. The machine can make a shell every 15 seconds.

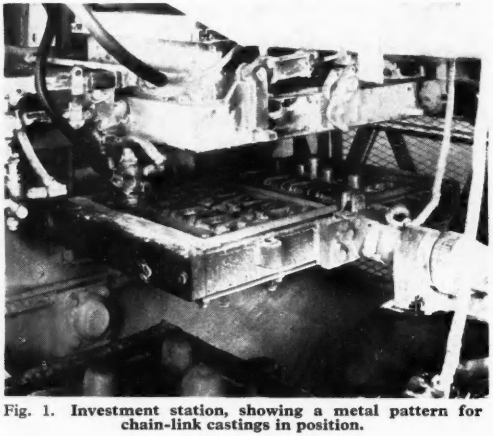

Fig. 1. **Investment station, showing a metal pattern for chain-link castings in position.**

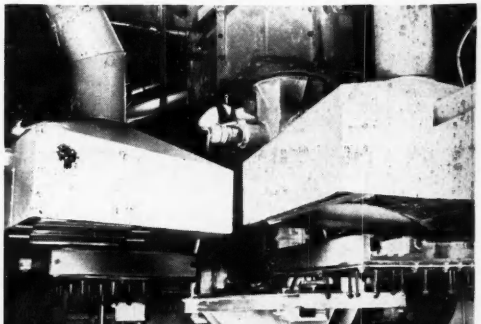

Fig. 2. **Curing stations for producing the hardness desired.**

The maximum pattern size for the new shell-moulding machine is 20 in. by 30 in. Ordinarily, this permits the cope and drag shell to be made on each pattern plate. The metal pattern with heaters and supports can be readily changed. As shells are removed from the moulding machine (Fig. 4), cores are set and the drag half is placed on a fixture in the closing machine.

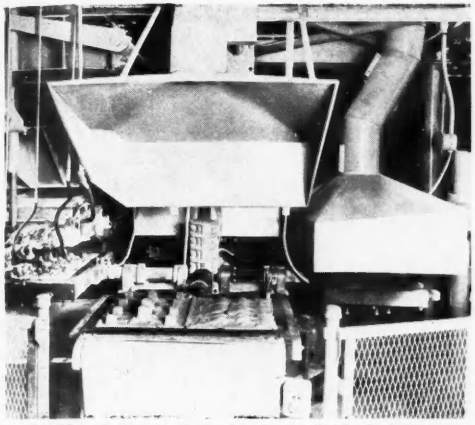

Fig. 3. **The ejector station, showing a finished shell (cope half and drag half) ready for removal.**

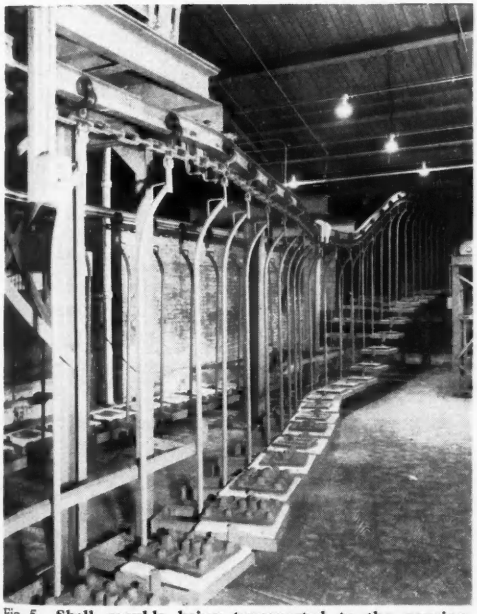

Fig. 5. **Shell moulds being transported to the pouring station on a trolley conveyor.**

Adhesive is then applied around the mould cavity. The cope half is put into place, and an air-operated mechanism holds the two halves together while the adhesive sets. Close tolerances between the cope and drag eliminate objectionable fins in the finished casting. The shells are placed on a trolley conveyor (Fig. 5) for pouring. Small castings which are poured horizontally normally require no support. Sand, gravel, or shot can be used to support the shell, if necessary.

The use of shells permits a virtually dustless shake-out of castings (Fig. 6). Waste sand and cores are quickly disposed of, in contrast with the large volume of hot sand which must be handled and reclaimed in a conventional system. Castings produced by this method are smooth, clean, and accurate, resulting in a possible reduction in cleaning-room costs. A minimum of sprues or risers increases the yield of castings, and their greater accuracy and smoother finish substantially

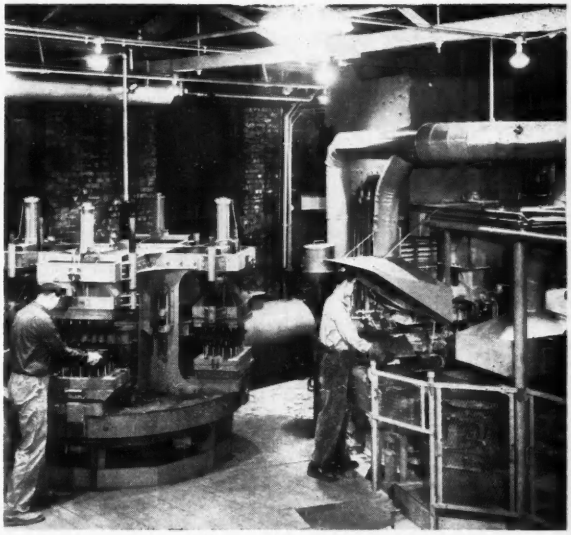

Fig. 4. **Four-station shell-moulding machine** (right), **with shells in position in the four-stage shell-closing machine** (left).

reduce the cost of machining operations. In fact, machining can sometimes be eliminated, while small parts of intricate design or thin sections can now be cast instead of forged or machined.

It is reported that outstanding success has been achieved on small castings in all types of foundries, ferrous and non-ferrous. The system is particularly adaptable for costly alloys, where the amount of metal used must be carefully controlled. Moreover, the high quality of the finished casting can be maintained by the operators through simple adjustment of controls, and the thickness of the shell mould can be varied by changing the temperature of the pattern and the retention time at the investment station. In addition, the shell-closing machine can be adjusted to assure a strong bond between the shells, while the speed of the pouring conveyor can be regulated to provide optimum cooling time for the castings.

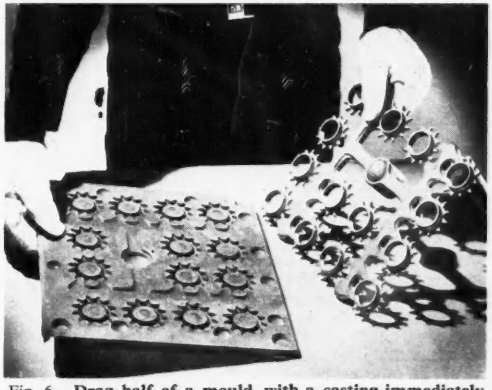

Fig. 6. **Drag half of a mould, with a casting immediately after shake-out.**

The new shell-moulding system, which is push-button controlled, can be laid out compactly and fitted into a limited space. This flexibility permits economy in the arrangement of sand-preparation equipment, moulding and closing machines, storage, pouring, and shake-out conveyors.

GERMANY

# The Contact Resistance of Sliding Contacts

By F. SCHRÖTER. (From *Elektrotechnische Zeitschrift* (*ETZ*), Part A, Vol. 76, No. 14, July 11, 1955, pp. 498-503, 7 illustrations.)

*In previous reports [1, 2] by the author on the contact resistance between brush and commutator, the influence of the oxide film at the metal surface was not given sufficient attention. The present article gives a detailed investigation of this effect.*

THE contact resistance of a sliding contact depends on prevailing operating conditions and primarily on current density. If this is varied, the contact resistance also changes very rapidly, since the temperature of the contact area adapts itself immediately to the new load. Thereafter, the variation continues until the temperature of the brushes is also adjusted to the altered conditions. The final state, however, is reached only when the commutator surface has gradually been modified, e.g., strongly oxidized as a result of the temperature rise under the changed operating conditions.

Thus, two very different curves for the voltage drop as a function of load are obtained, according to whether the tests are performed in rapid succession or only after each new equilibrium condition appears. Only if measurements are taken in rapid succession does the oxide film remain virtually unaltered throughout the tests.

Before carrying out such tests, the commutator was polished and the brushes were run for 48 hours under maximum current. In view of the above considerations, it was decided to take measurements at 2-minute intervals and to determine the contact voltages with gradually decreased currents, since with increasing currents the contact surface may be substantially altered in some cases, even after the first few seconds, whereas with decreasing currents the surface alteration requires a much longer period. As there was some scatter in the results of one of the test series, a total of 10 test series was taken and average results were calculated.

It was found that the conductance of the sliding contact varied approximately in the ratio of 1 : 4 within the load limits chosen, i.e., from 19 to 205 A. It is not possible to attribute this to the negative resistance/temperature coefficient of the carbon brushes, since the coefficient is far too small to produce such a variation, even if very high peak temperatures at the contact points are assumed.

According to published data,[3] the negative resistance/temperature coefficient is highest for graphitized carbon. However, even at a temperature of 2800° C, the increase in conductance of the carbon is less than 1 : 4, ranging from 100% relative resistance at 0° C, to 41% at 1400° C and 32% at 2800° C.

The conductance of cuprous oxide, on the other hand, increases to a much greater extent with temperature, in accordance with the relation

$$G = A \exp(-B/T) \text{ or } \log_e G = \log_e A - (B/T) \quad \ldots \quad (1)$$

which is valid for semi-conductors, where $G$ = conductance, $A$ and $B$ = constants depending on the type and quantity of the foreign atoms in the lattice of the semi-conductor, and $T$ = absolute temperature [°K].

The temperature increase $\Delta\theta$ at the contact corresponds to the power loss $W$ [watts] occurring at the contact, so that, using a proportionality constant $c$, $\Delta\theta = c\,W$. Consequently, $T = T_0 + c\,V$, where $T_0$ is the commutator temperature during the test. Owing to the high heat capacity of the commutator, $T_0$ remains practically constant during measurements taken over a period of only a few minutes.

## DIFFERENCES IN POLARITY

The voltage drop of the " cathode " brush is usually greater than that of the " anode " brush. This is due to the rectifying layer between the oxide and the base metal. If the brush is a cathode, it acts as an insulating surface. The remaining conductive surface of the oxide film will therefore be more heavily loaded than it will be under the anode and hence will also have a higher voltage drop. Eq. (1) is valid for the non-rectifying surfaces, and it is now necessary to determine the numerical values for its parameters.

## CONDUCTANCE OF CATHODE BRUSH

By means of eq. (1) and the relation $T = T_0 + cW_C$, the logarithm of conductance can be expressed as

$$\log_e G_C = \log_e C - B/(T_0 + cW_C) \quad \ldots \quad \ldots \quad (2)$$

where $C = fA/d$, where $f$ = true contact surface [cm²] traversed by the current and $d$ = thickness of the oxide film [cm]. The commutator temperature $T_0$ has a measured value of 37° C = 310° K. The unknown quantities $C$, $B$ and $c$ can be determined experimentally as $\log_e C = 5{\cdot}531$, $c = 1{\cdot}75$, and $B = 698$. With these numerical values substituted in eq. (2), the contact loss $W_C$ and the conductance $G_C$ can be calculated. The comparison of calculated values of $G_C$ with measured values gives the following results:—

| | | | | | | |
|---|---|---|---|---|---|---|
| $G_C$, calculated, mhos | 116·3 | 92·6 | 73·4 | 49·6 | 30·6 | 26·6 |
| Relative error, % | +7·0 | +3·7 | −2·0 | +0·3 | −2·0 | 0 |

The agreement, at least at low loads, is very good. Nevertheless, the evaluation is unsatisfactory in two respects. Firstly, $\Delta\theta = cW_C$ gives much higher temperature rises than required by the cuprous oxide to alter its conductance to the desired extent, and, secondly, large temperature rises in the film signify a very high concentration of energy on a correspondingly minute contact surface. In this case, the resistance to the spreading out of the current in the carbon can no longer be neglected.

However, both of these objections can be eliminated by introducing the " diffusion " resistance. If this is regarded as a constant resistance in series with the film resistance, then it is apparent that the film conductance will have to vary much more appreciably than without the diffusion resistance, in order to obtain the same as the measured overall conductance $G_C$. This will then also require a higher temperature difference $\Delta\theta$. On the other hand, the electric power loss $W_C$, which causes heating of the film, will be reduced by an amount corresponding to the diffusion resistance, so that in this respect the temperature rise will be less marked.

For further assessment, it may be noted that cuprous oxide has a conductivity $G$ which depends on temperature in accordance with the relation

$$\log_e G_1 - \log_e G_2 = k\,[(1/T_1) - (1/T_2)] \quad \ldots \quad (3)$$

where $k \cong 700$ for a high oxygen excess; with a lower oxygen content[4], $k$ may reach values up to 3500.

When the contact area is reduced and the diffusion resistance increases, the temperatures obtained from $\Delta\theta = cW_C$ and from eq. (3) both increase and tend towards the same value. However, it is not possible to calculate the value of diffusion resistance at which they coincide, because the equations contain too many unknown quantities. Moreover, the diffusion resistance of carbon also depends on temperature, although to a much lesser degree. As it was not possible to show with certainty any influence of frictional heat on the temperature rise of the contact points, the influence of friction will be neglected in the following considerations.

The only possible way to investigate how electrical losses influence the conductance of the cathode, was to evaluate eq. (2) with a large number of values for the

diffusion resistance $R_a$, trying each value with different assumptions for the mean temperature rise in the carbon, until sufficient agreement was found between measurement and calculation. Thus, it was established that $R_a = 0{\cdot}005$ ohm (in the cold state) and 20% less at the maximum current intensity of 205 A, corresponding to a mean temperature rise of 200° C in the diffusion resistance. The coefficients of eq. (2) thus obtained are

$$\log_e C = 9{\cdot}584,\ B = 1910, \text{and } c = 0{\cdot}84.$$

The greatest temperature rise in the film then has a value of 142° C. The deviations between the measured values of film conductance and those calculated with the three coefficients indicated above are given in Table I.

TABLE I.

| Current intensity, A | 205 | 145·5 | 102·3 | 58·3 | 19 | 1 |
|---|---|---|---|---|---|---|
| Film conductance, measured, mhos | 249 | 166 | 108 | 65·6 | 35·4 | 30·7 |
| Film conductance, calculated, mhos | 212·5 | 149·8 | 109·3 | 65·3 | 36 | 30·7 |
| Correction factor | 1·17 | 1·12 | 0·99 | 1·01 | 0·98 | 1 |

In the lower range of loads, the calculated and measured values show very good agreement. The deviations for the two highest load conditions can be explained as follows :—

As long as the film temperature is higher than that of the carbon, the heat generated in the diffusion resistance $R_a$ cannot flow down to the contact point. However, the film resistance falls off much more rapidly than $R_a$, so that a greater proportion of the loss will occur in the carbon (Fig. 1). Therefore, the temperature of the latter will rise more rapidly and, as soon as it exceeds the film temperature, heat will also flow from $R_a$ through the contact point in the film and will contribute to its heating up. Of the power consumed in the diffusion resistance, about 12% is sufficient to account for the discrepancy in the calculations for the two highest load conditions.

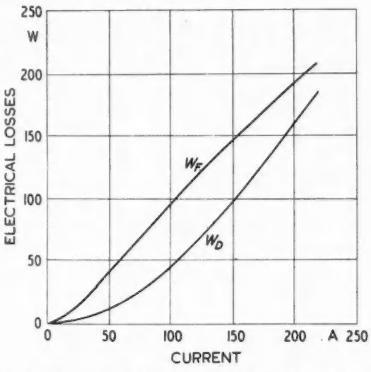


Fig. 1. **Electrical losses at the cathode as a function of current.**
$W_F$ = losses in oxide film.
$W_D$ = losses in diffusion resistance.

From eq. (3), a calculated value of $k = 817$ is obtained. The calculated temperature rises in the film and the carbon are not very high and agree with the observation that, with high overloads, the brush will glow, whereas the point of contact with the commutator remains dark.

*Thermal considerations:—*

According the the above calculation, there is a mean temperature rise of 142° C in the film, due to electrical losses at the highest load. To heat the thin film to this extent, it is necessary to have a high current density, i.e., a small contact area. The heat capacity of the film is so low that the heating-up period may be neglected. Under equilibrium conditions, in a film layer of thickness d$x$ the heat $Q_1$, generated by the current $i$ per unit time, is equal to the heat leaving the layer because of the temperature difference d$t$ existing across it, hence

$$Q_1 = i^2 \rho \frac{\mathrm{d}x}{F} = \lambda \frac{F}{\mathrm{d}x}\mathrm{d}t \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

where $F$ is the contact area, $\rho$ is the specific conductance, and $\lambda$ is the thermal conductivity. Therefore, with $S = I/F$ = true current density, $I$ = total current through the brush, $E = S\rho d$ = voltage drop across the film of thickness $d$,

$$\int_{t_2}^{t_1} \mathrm{d}t = t_1 - t_2 = \frac{\rho i^2}{\lambda F^2} \int_0^d x\,\mathrm{d}x = S^2 \rho\, d^2/2\lambda$$

$$= ESd/2\lambda = EId/(2F\lambda) \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

where $F$ = total area of all contact points of the brush. For cuprous oxide, $\lambda \cong 0{\cdot}01$ W/cm °C sec; the film thickness[5] may be taken as $d = 5 \times 10^{-6}$ cm, and a simple integration shows that $t_1 - t_2 = 3/2\ \Delta\theta = 1{\cdot}5 \times 142 = 213$° C. Therefore, from evaluations based on Table I, with $I = 205$ A and $E = 0{\cdot}825$ V for the cathode brush, the total contact area is

$$F = EId/[2\lambda\,(t_1 - t_2)] = 1{\cdot}98 \times 10^{-4} \text{ cm}^2.$$

For $n$ contact surfaces regarded as circles of diameter $2a$,

$$F = n\pi a^2 = 1{\cdot}98 \times 10^{-4} \text{ cm}^2. \quad \ldots \quad \ldots \quad (6)$$

The diffusion resistance $R_a$ of $n$ points in a macroscopic area of contact $\pi A^2$ (radius $A$) was calculated by Holm[6] as

$$R_a = \rho \left[ \frac{0{\cdot}9}{4\pi n a} \tan^{-1} \frac{1{\cdot}23A}{a\sqrt{n}} + \frac{1}{2\pi A}\left(1 - \frac{1{\cdot}23}{\sqrt{n}}\right) \right].$$

If $n$ is not a very large value, and $a$ is much less than $A$, then $\tan^{-1}\left[1{\cdot}23A/(a\sqrt{n})\right] \cong \pi/2$, and the second term in the square brackets can be neglected. Thus,

$$R_a \cong 0{\cdot}125\ \rho/na. \quad \ldots \quad \ldots \quad \ldots \quad (7)$$

In the case considered, the resistivity of the carbon was $\rho = 0{\cdot}005$ ohm-cm and $R_a = 0{\cdot}005$ ohm. Hence,

$$na = 0{\cdot}125\ \rho/R_a = 0{\cdot}125.$$

Since $F = 1{\cdot}98 \times 10^{-4}$ cm², $a = 5{\cdot}05 \times 10^{-4}$ cm; therefore, there are $n = 250$ contact points over the surface of 14 cm².

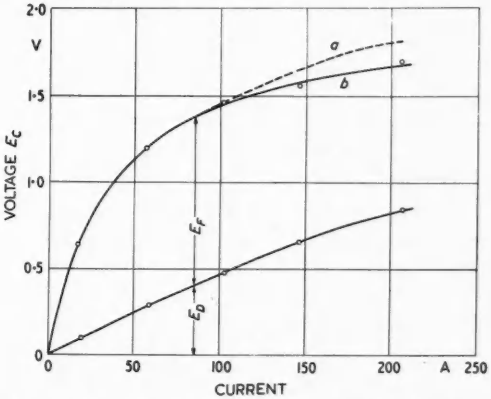


Fig. 2. **Voltage drop at the cathode as a function of current.**
$E_F$ = voltage drop in oxide film.
$E_D$ = voltage drop in diffusion resistance.
Curve (*a*): Calculated voltage drop.
Curve (*b*): Calculated voltage drop, taking into consideration the additional heating due to diffusion resistance.

This number is reduced if the contact points are oblong instead of round, which seems plausible from an inspection of the paths on the commutator and their characteristic polish. An oblong contact surface can be represented by an ellipse. If its two axes are in the ratio of, for instance, 1 : 25, the diffusion resistance will be only one fifth of its value for a circle of the same area, so that in this case $a = 2{\cdot}52 \times 10^{-3}$ cm, and $n = 10$ contact points on the entire surface. The minor axis of $10^{-4}$ cm is still adequately large in relation to the film thickness of $5 \times 10^{-6}$ cm for edge effects to be disregarded. The points of contact are, of course, of various sizes and this results in a non-uniform current distribution, particularly at high loads, when most of the current may be concentrated at a single point.

Fig. 2 shows the voltage drop at the cathode, as determined from eq. (2), using the above coefficients and a diffusion resistance $R_d = 0{\cdot}005$ ohm. The test points are also indicated. The agreement is now considerably better than in Table I, and proves that the contact resistance of the cathode is that of a semi-conductor with the characteristic values of cuprous oxide, connected in series with a diffusion resistance within the carbon. Although individual data may vary from case to case (e.g., the film thickness and its thermal conductivity) the basic relations will not be altered by these factors.

## Conductance of Anode Brush

The points of the oxide film which have a rectifying effect are no obstruction to the electrons from the parent metal. The total conductance of the anode film is therefore the sum of the conductances of the neutral points (through which the current to the cathode also flows) and the conductance $G_R$ of the rectifying positions.

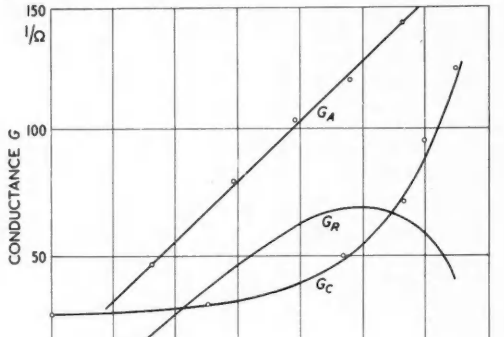


Fig. 3. **Conductance $G$ plotted against contact voltage $E_A$.**

It is first necessary to determine the anodic currents flowing along these paths. This is done by plotting the total conductances $G_A$ and $G_C$ measured at the anode and the cathode against the corresponding contact voltage $E_A$ (Fig. 3). For the same voltage values, the neutral positions pass the same currents towards the anode and the cathode. Therefore, for each contact voltage $E_A$, the conductance of the rectifying positions can be determined as $G_R = G_A - G_C$. Then, $E_A$ and $G_R$ can be used to determine the corresponding current $I_R$.

The curve of the current $I_R$ plotted against contact voltage follows in its lower portion the course of the typical characteristic for copper-oxide rectifiers (Fig. 4). The rectifying action is a boundary effect which can occur wherever the oxide touches another conductor.

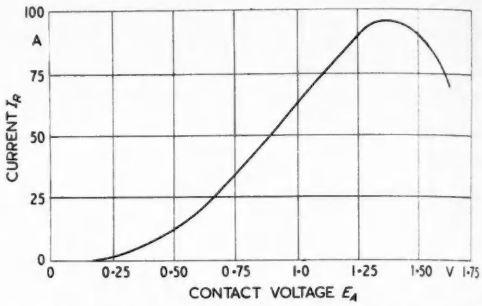


Fig. 4. **Current $I_R$ plotted against contact voltage $E_A$.**

Owing to the presence of oxygen atoms, electrons are available for conduction. If they are lacking, then there will be no electrons available in the semi-conductor for current to flow out of it, whereas sufficient electrons can be supplied by the conductor for the current in the opposite direction.

In the present case the oxide is between the parent metal of the commutator and the running surface of the brush. As the oxygen enters from the outside, there will be a lack of excess electrons at the internal boundary on the commutator.

Commercial rectifiers have oxide layers of up to $10^{-2}$ cm thickness behind their boundary layer. This resistance in series has a voltage drop which inevitably is detrimental to rectifier efficiency. On the commutator, however, the film thickness is only between $10^{-5}$ and $10^{-6}$ cm, so that in this case the current rise is much steeper than in rectifiers. Also, cooling conditions are more favourable on the commutator, and this explains why the load-carrying capacity of the film on the commutator is higher than in the usual types of rectifiers.

*Breakdown of the rectifying action* :—In Fig. 4, the curve of current $I_R$ shows a point of inflection at about 1·4 V, which indicates a breakdown of the rectifying effect. This may be due to the thermal expansion of the carbons at the netural contact points.[7] Using an expansion coefficient of $7 \times 10^{-6}$ per °C, a rough calculation shows that a temperature rise of 200° C in the diffusion resistance of the carbon will cause a bulge of about 1·4 microns per millimetre of depth of carbon heated. The bulging of the highly loaded neutral contact points may therefore cause a lifting of the brush at the less heavily loaded rectifying positions. If the brush is overloaded to such an extent that glow at the contact points can be observed, the heated zone is some millimetres in size. It is also conceivable that the rectifying positions are destroyed through overloading by diffusion of excess oxygen atoms into the rectifying boundary layer at high temperatures, which then allow current to flow in both directions. This may be an alternative explanation for the excessively high values of conductance found for the cathode under the highest load conditions.

## Conclusions

As the netural contact points become hotter under the cathode than under the anode, the commutator copper at such points oxidizes more easily. This explains the difference in the polish of the commutator at places where the anode and cathode paths do not coincide.

The higher load of the cathode contacts also explains why they are more apt to give trouble. The negative resistance/temperature coefficient of the oxide, finally, is responsible for the fact that the division of the current gradually becomes uneven at higher loadings, first within one brush and then also among the brushes connected in parallel in the brush-gear of an electrical

machine. The non-uniformity is greater with thick oxide films, i.e., the weaker is the polish produced by the brush. The influence of the diffusion resistance is considerable, particularly at higher loads, but does not appreciably alter the shape of the current/voltage curve. A different thickness of the oxide film will not appreciably alter the voltage drop of the brushes, since on average a thick film becomes hotter than a thin one, firstly because of its poorer conduction of heat and secondly because of the heating power, which increases with higher voltage drops.


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FRANCE

# High-Temperature Fatigue-Testing Machine


By G. VIDAL and P. LANUSSE. (From *La Recherche Aéronautique*, No. 45, May-June 1955, pp. 45-51, 11 illustrations.)


THE rotor blades of aircraft gas turbines are subjected to constant centrifugal tensile and superimposed alternating stresses of variable amplitude, dangerous near resonance conditions. For the testing of blade materials, these conditions are simulated on tensile fatigue-testing machines such as the Amsler "Vibrophore," which operates at high frequencies with small testpieces, so that tests can be undertaken economically, i.e., rapidly and with small quantities of experimental materials or with testpieces from blade roots. A controlled furnace, in principle of the type used in creep-testing machines, is easily installed and keeps the high temperature rigidly constant, a necessity because fatigue properties are greatly affected by small temperature variations in the high-temperature range. The extreme values of the imposed load must also be kept strictly constant. This offers no difficulty at room temperature, when the Vibrophore is set to a given static mean stress and when one of the extreme values of the oscillating load is automatically controlled by the machine. At high temperatures, however, this preset static mean stress will be reduced appreciably by any creep of the specimen or temperature fluctuation in the chucks projecting from the furnace. Hence, a special automatic control has been added. Moreover, recorders of sinusoidally alternating load and temperature permit a complete check on the functioning of the machine during any test.

The 10-ton Amsler Vibrophore, used in these tests because of its versatility and the large furnace space available, is supplied with a 10-ton and a 2-ton dynamometer, but the 0·4-ton dynamometer of a similar smaller machine can also be fitted. With the 2-ton and 0·4-ton dynamometers, the extreme values of the alternating load can be kept constant to within 4 lb and 0·8 lb respectively, so that even very small specimens can be tested accurately. The principle of the machine is shown in Fig. 1.

Two masses $M$ and $m$ are connected by two elastic elements, i.e., the dynamometer $D$ and the testpiece $E$. The system is made to vibrate freely at its fundamental frequency. A permanent-magnet inductance pick-up $P$ operated by the deflections of the dynamometer $D$ produces an alternating e.m.f. of the same frequency as the resonant system and of a maximum amplitude proportional to the load range. Amplified by the electronic system $S$ this e.m.f. controls the exciting electromagnet $A$, so that the vibrating system is always driven at its resonant frequency, even if this frequency changes with time. The extension of the dynamometer, i.e., a quantity proportional to the instantaneous applied force, is amplified by a rotating mirror $R$, which projects onto a graduated scale $G$ the light from the filament of lamp $L$ through an optical system $O$. A cursor $I$, connected with a photoelectric cell $Q$, is set on scale $G$ and limits one of the extreme values of the applied stress, i.e., $F_{max}$ or $F_{min}$, because a photoelectric current opposing the pick-up current is generated as soon as the light travelling along scale G reaches the position of the cell $Q$. Thus, presetting of the static mean stress $F_0$ by means of the screw adjustment $V$ or $V'$ and automatic control of either $F_{max}$ or $F_{min}$ determine the range and values of the sinusoidal applied force. Unfortunately, since the elastic system is extremely rigid, even a small extension of the test assembly, such as that produced by a simple current of air blowing on the chucks outside the furnace $F$, will change the preset mean stress $F_0$ beyond permissible limits and, therefore, even more so the uncontrolled extreme value of the applied force. Hence, the static mean tension must also be adjusted automatically.

The control for automatic adjustment of static mean stress[1] consists of a pilot system $J$ and a follower system $X$-$Y$-$Z$-$V$, which corrects the mean stress at a speed increasing with the amplitude of its fluctuations. Such a system eliminates hunting, yet has a quick response, especially when fracture is preceded by an appreciable deformation due to creep under alternating loads at high temperatures. With the machine as supplied, an

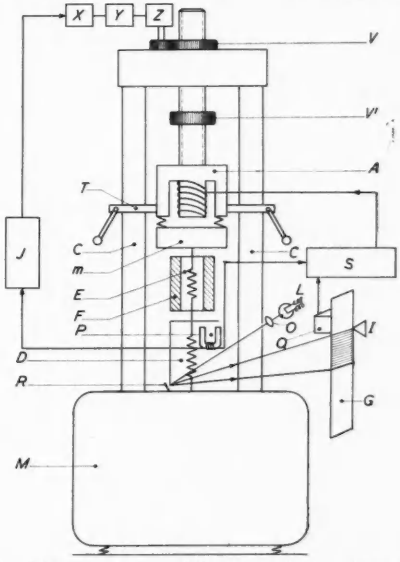


Fig. 1. **Schematic layout of fatigue-testing machine used.**

accidental change in the mean stress $F_0$ produces twice this change in the range of alternating stress, and hence twice this change in the e.m.f. of the pick-up $P$; the change in e.m.f. is used as a correction of $F_0$.

This arrangement avoids any vibrating contacts, and, because of the relatively high detecting e.m.f., merely requires the use of a conventional type of amplifier.

The follower system consists of a d.c. motor $X$, developed by O.N.E.R.A., and two reduction gears $Y$ and $Z$, the output shaft engaging the upper gear and nut $V$ on the central spindle of the Vibrophore; the total reduction is 1 in 150,000 and completely eliminates all hunting effects. At the maximum speed of the machine, the servo-system maintains a constant stress $F_0$, even when the rate of deformation is about 3 microns per second, i.e., when a testpiece of 30 mm gauge length has a creep rate of 36% per hour or when chucks of 300 mm total length are heated or cooled by 1° C per second. Under repeated or fluctuating stress the reaction exerted on the nut $V$ always has the same direction, so that the locknut $V'$ need not be tightened. During normal operations, on the other hand, the electromagnet $A$, once set with the aid of $V$, must be rigidly secured to the columns $C$ by means of the traverse $T$. This cannot be effected automatically, but any disturbing shocks may be avoided if the outer ends of the traverse are held elastically to the columns, e.g., if a couple is applied to each end of $T$ by means of a rubber stop and supporting roll.

The range of applied load determines the e.m.f. in the pick-up $P$. This e.m.f. may be recorded as a check on any irregularity of operation, e.g., failure of the optical system, overrunning of stops, or defects in the automatical control. With the electronic circuit used, a recorder, operating two traces, can be employed to check both the essential test parameters, i.e., temperature and range of loading.

The condition of strictly constant temperature demands a relatively long furnace $F$; the electric furnace adopted for temperatures up to 1000° C has an internal diameter of 35 mm, a length of 280 mm, two-stage continuous rheostatic control, and automatic temperature regulation. During one year of service, it has worked without failure to limits of ±1° C. A similar furnace serves for fatigue tests at 1150 to 1200° C.

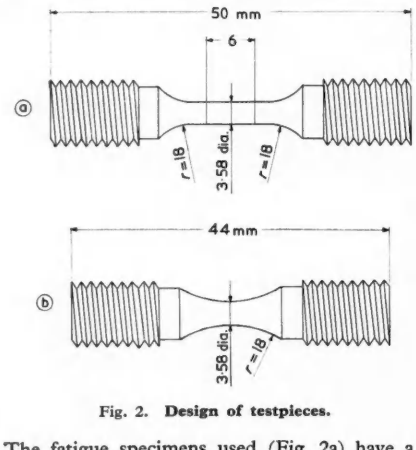


Fig. 2. **Design of testpieces.**

The fatigue specimens used (Fig. 2a) have a test cross-section of 10 mm² and are machined from 9-mm bar, the gauge length being ground longitudinally. As there is no danger of buckling, the diameter of the chucks outside the furnace has been reduced as much as possible. Thus, very little heat is lost and the effect of any imperfect axial alignment is minimized by the elasticity of the shanks. For temperatures below 800° C the grips are made of a special 80/20 nichrome alloy, while for higher temperatures cobalt-base ONERAL alloys[2] are used. Specimens of ceramic materials and cermets have been subjected at 1150 to 1200° C to repeated and fluctuating bending tests (Fig. 3).

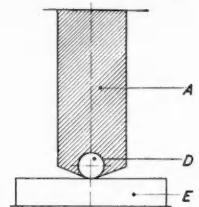


Fig. 3. **Testpiece and chucks for fluctuating bending tests at temperatures above 1100° C.**

The test bar $E$, of 6 × 6 mm cross-section and 31 mm length, is supported near its ends on an anvil $C$ of "Chromal"[3] and loaded at the centre by means of a round bar $D$ of sintered alumina, the anvil and loading bar being mounted on shanks $A$ and $B$ of sintered alumina, 15 mm in diameter. A load of 1 kg thus produces a maximum bending stress of approximately 20 kg/cm².

## Typical Test Results

Table I gives the fatigue limits of eight specimens of cast ONERAL cobalt-base alloy[2] and of forged ATGS Nimonic alloy (74·8 Ni, 18·7 Cr, 1·41 Al, 2·44 Ti, 1·45 Fe, 0·89 Si, 0·06 Mn), tested under identical conditions at high temperatures. With the equipment operating at 5650 cycles per minute the shorter design of testpiece shown in Fig. 2b was used.

Table I. Results of Fatigue Tests.

| Temperature and stress range | ATGS | | ONERAL | |
|---|---|---|---|---|
| | Hours to fracture | Cycles to fracture × 10³ | Hours to fracture | Cycles to fracture × 10³ |
| 800° C, 2 to 34 kg/mm² | 197 | 65,149 | 120 | 40,176 |
| | 154 | 52,113 | 52 | 16,700 |
| | 113 | 38,277 | >145 | >46,665 |
| | 92 | 31,141 | — | — |
| | 130 | 43,261 | — | — |
| 750° C, 2 to 47 kg/mm² | 169 | 57,192 | — | — |
| | 145 | 49,834 | — | — |
| | 122 | 41,901 | — | — |

In the case of the forged ATGS alloys, heat treatment before final grinding comprised 8 hours at 1080° C, followed by air cooling, and 16 hr at 700° C, with subsequent air cooling. The results show only slight scatter and illustrate the high fatigue strength of this material, even at 800° C. Metallographic examination of an axial section near the fracture revealed pronounced intergranular cracks. The cast ONERAL alloy has a similar fatigue strength at 800° C.

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# High-Current Arc Erosion of Electric Contact Materials

By W. R. WILSON. (From *Power Apparatus and Systems* (*AIEE*), No. 19, August 1955, pp. 657-664, 8 illustrations.)

*Although there have been many investigations in the field of electric contacts, surprisingly little has been published concerning the high-current region in the neighbourhood of 5000 A and over. Furthermore, conclusions reached from experience at low currents cannot be applied at high currents without specific verification. The investigation of arc erosion herein described is one part of a fundamental programme which has been under way in the high-current region for several years.*

TESTING for arc erosion in the high-current range is very different from testing in the low-current range. To obtain an adequate measure of loss of material, it is usual to operate a 100-A contactor 100,000 times. By comparison, a 20,000-A arc, held for 0·1 sec, will disintegrate a copper busbar $\frac{1}{2}$ in. long, $\frac{1}{4}$ in. thick, and 2 in. wide.

In this investigation it was desired to eliminate certain disadvantages of selecting one particular circuit-breaker as being representative, and mounting each pair of contacts in it for test. These disadvantages include the difficulties of (1) controlling arc duration; (2) eliminating or reproducing contact bouncing or vibrations, so that a consistent curve of gap length versus time could be maintained; and (3) synchronizing the exact instant of contact opening with the desired point on the current wave. To eliminate these extraneous factors and to obtain reproducible and reliable arc-erosion data, a new arc-erosion testing facility was developed.

## TEST EQUIPMENT

Fig. 1 is a schematic diagram of the test equipment used. The equipment passes a single half-cycle of controlled current through an arc struck between the contacts. To eliminate mechanical opening-stroke variations, the contacts are held stationary at a fixed gap, generally from $\frac{1}{64}$ to $\frac{1}{2}$ in. A high-voltage impulse generator has often been used to break down the gap and to initiate the arc. In other cases, after comparative tests have established that the arcing region is not contaminated, the arc is initiated by means of a fuse wire. Energy for the arc which follows is derived from a large capacitor bank charged through rectifiers to

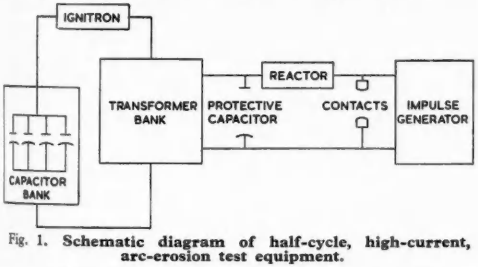


Fig. 1. **Schematic diagram of half-cycle, high-current, arc-erosion test equipment.**

several kilovolts direct current. A portion of the trigger voltage is used to fire an ignitron, which discharges the capacitor bank through a transformer bank to step up the current. A reactor is used to resonate the capacitor bank to yield the desired base frequency of the half-cycle of current. To prevent the impulse voltage from damaging the transformers, a capacitor is connected across the secondaries to form, with the reactor, a low-pass filter. Magnetic and cathode-ray oscillographs are used to record arcing voltage and current, and extensive additional instrumentation is available, as needed.

*Condition of Test :—*

All arc-erosion data reported on the graphs of this paper were taken with $\frac{1}{2}$-in. diameter contacts with a 2-in. radius crown. The bulk of the data, such as for the elements of Fig. 2 and the sintered alloys of Fig. 3, was obtained with a $\frac{1}{32}$-in. gap established between the contact surfaces before each arc. Generally, each pair of contacts was subjected to six arcs of one half-cycle duration on a 72-cycle base. Because of variations in arc voltage, the crest current in the metallic arcs varied from about 20,000 to 25,000 A. For carbon the current was exceptionally low, reaching a crest of only 12,000 A. Based on the calculation method to be described later in this paper, compensation was made for these variations by reporting the data in cubic centimetres of material lost per kA-sec. The adjustments were a matter of a few per cent for the metals. For convenient reference, the average 72-cycle base wave was equivalent in ampere-seconds to a 12,000-A r.m.s. half-cycle on a 60-cycle base. Finally, because the volume of arc material lost is of more engineering importance than the weight, the weights were converted to approximate volumes.

Fig. 4 presents typical curves of arc erosion in terms of material loss versus the number of arcs that had been applied in succession. Although there are appreciable variations between weight losses on successive tests, the points in general follow straight lines. These variations can often be correlated during test with pieces of contact material which gradually lose their support and then finally drop off during one of the arcs. That the erosion rate does not decrease as the number of arcs increases is evidence that composition of the sintered alloy materials does not change markedly during arcing. With the lower melting temperature materials, large protuberances which formed were filed off to maintain essentially flat surfaces.

## THEORY OF EROSION PROCESSES

It should perhaps first be pointed out that erosion of contacts is a complex, non-linear space-distribution type of problem involving such factors as bubbles bursting through the liquid surface of the contacts in the midst of turbulent blasts of gas. Heat transfer and viscosity phenomena are involved at temperatures so high that they cannot be studied except in the arc. Consequently, calculations are able to establish orders of magnitude only, and to determine whether or not certain processes are active. It is not to be anticipated that the theory evolved will predict measured results with any degree of precision.

*Arcing Medium :—*

In the order of 1 microsecond[1] as arcing current starts to flow, portions of the contact surfaces reach temperatures at which the metal evaporates. The gaseous volume of the metal vapour which has issued from these surfaces by the end of a high-current half-cycle arc is surprisingly large.

With copper contacts carrying the 12,000-A arc current, the weight of metal vaporized per operation is about 1 gram (see Fig. 4). At the typical arc temperature of 5000°K and at atmospheric pressure, this weight of copper as a gas would occupy a volume of about 7500 cm$^3$. It therefore appears certain that the original gas or liquid between the contacts must be swept out very early in the half-cycle by this metallic gas which flows from the surfaces. Thus, the arc, under the conditions of test, must flow through a gas consisting almost solely of the vapour from the contacts. This is an explanation of the fact that contacts tested at high current showed the same erosion rates in air and in oil.

*Energy Distribution :—*

The classical picture of the voltage distribution in an arc is that of abrupt voltage drops which occur over microscopic distances at the cathode and anode, together

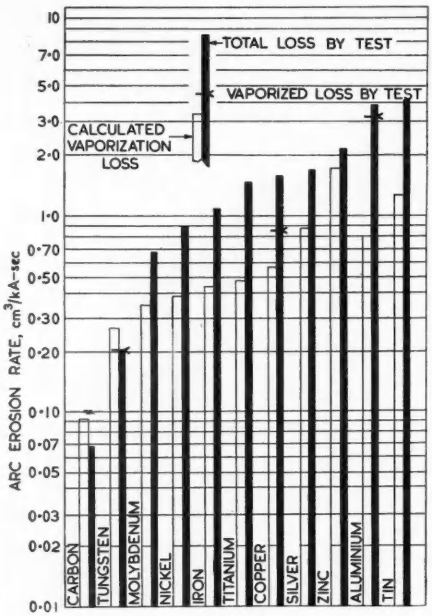


**Fig. 2. Arc erosion of elements in their order of excellence, as determined by test, and comparison of measured erosion rates with calculated vaporization rates.**

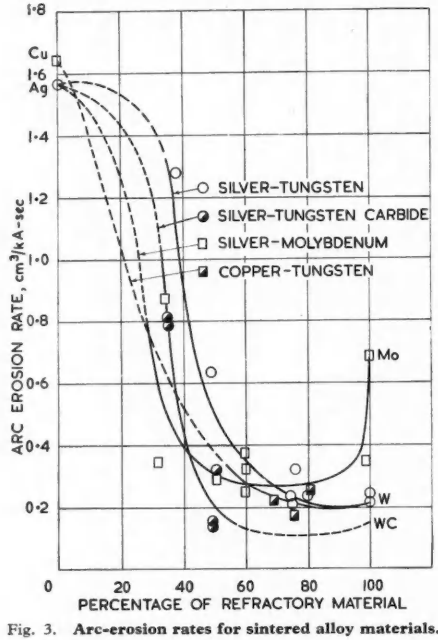


**Fig. 3. Arc-erosion rates for sintered alloy materials.**

with a gradual linear change of voltage along the axis of the column. Because the same current flows through all drops, energy release at the contact surfaces is intense.

In working towards a more complete general understanding of arc processes, Cobine[2] has used the data presented in this paper to establish that vaporization is one of the main erosion processes at the anode of high-current arcs. He was also able to make new determinations of anode surface temperatures. In an earlier paper, Holm[3] concluded that erosion losses at the cathode of a high-current arc also result primarily from vaporization. Both investigators postulated that the electric energy dissipated in the region of the surface-voltage drop (anode and cathode drops respectively) produces the vaporization, and both comment that reliable data on the magnitudes of these voltage drops are not available. There are several mechanisms whereby electric energy dissipated in the anode and cathode drops is delivered to the electrodes. Their relative importance has apparently not yet been established.

*Vaporization-Rate Equation :—*

The continuous drain of vaporization energy from the region of the cathode and the anode must apparently be replaced by electric energy in nearly the same volume. This will be found consistent with the test results (Fig. 5) and seems reasonable because of the relatively small amount of heat that could travel long distances against the flow of vaporized material and through the relatively low axial temperature gradients which exist along the column away from the surfaces.

The electric energy input near the contact surfaces is therefore

$$W = (E_c + E_a)\,IT \qquad \ldots \quad \ldots \quad (1)$$

where

$W$ = total energy input at electrodes [watt-seconds]
$E_c$ = cathode drop [V]
$E_a$ = anode drop [V]
$I$ = arc current : average of absolute magnitude [A]
$T$ = duration of arc [sec]

The metal vaporized is

$$V = \frac{W}{\rho JH} \qquad \ldots \quad \ldots \quad \ldots \quad (2)$$

where

$V$ = volume of metal vaporized [cm³]
$H$ = heat of vaporization [cal/gm]
$J$ = heat equivalent = 4·18 [joules/cal]
$\rho$ = density of contact material [gm/cm³]

Combining eqs. (1) and (2) yields the vaporization rate in cm³ of contact material lost per kA-sec of arc current

$$R = \frac{1000V}{IT} = \frac{1000\,(E_c + E_a)}{\rho JH} \qquad \ldots \quad (3)$$

where $R$ = erosion rate [cm³/kA-sec].

This vaporization-rate equation is derived because it appears to be a rough physical constant of the material, depending for its value upon other physical constants.

Although separate values for the anode and cathode drops are difficult to obtain, an approximate value for their sum, as required by eq. (3), can be obtained by measurements on short arcs. The calculations of this paper are based on the fact that both the axial voltage gradient along the column and the sum of the cathode and anode drops are reasonably independent of current magnitude. It can be assumed, for ease in approximate calculations, that in the high-current range of stationary arcs in atmospheric air the sum of the anode and cathode drops is 25 V for all materials.

## Comparison of Measured Erosion Rates with Calculated Vaporization Rates

Before checking the vaporization-rate equation against the data, it is of interest to see the range over which the results might lie. In a previous paper,[7] the author presented extensive data on the arcing life of silver contacts in the range from 5 to 35 A. At 20 A, for example, the volume of silver lost per operation was

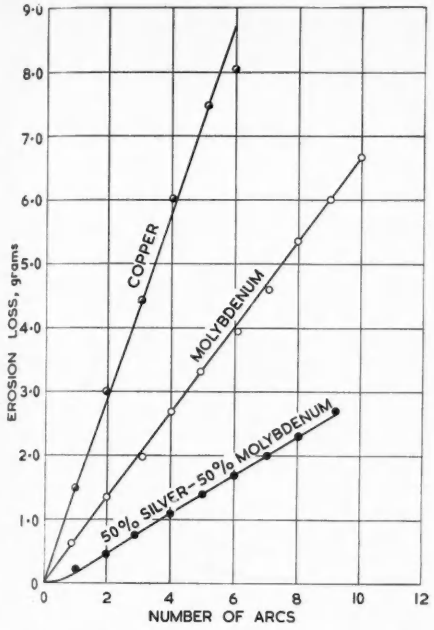


Fig. 4. **Arc-erosion loss as a function of the number of half-cycle arcs.**

about $10^{-9}$ cm³. In the present tests it is 0·1 cm³. This is an erosion change of $10^8$ to 1 resulting from a current change of $10^3$ to 1. The rate in cm³/kA-sec was of the order of $10^{-5}$ at 20 A, in comparison with 1 at 12,000 A.

According to Holm,[3] the primary reason for this great variation in erosion rates is that most of the heat is conducted away through the contacts at low currents and moderate spacings and therefore is not available to vaporize material. As currents are raised and heat is introduced more rapidly, the vaporization region is reached in which heat conduction becomes negligible, and effectively all of the heat must be dissipated by vaporization. In Holm's work this region started in the order of 1000 to 10,000 A. With certain small contacts[4] between which arcs occur at extremely small spacings, the energy input is concentrated in such a minute space that the vaporization region would occur at much lower currents. The primary assumption made throughout this paper is that only the high-current vaporization region is being considered.

*Sample Calculation with Copper :—*

For a sample calculation with the vaporization-rate equation, consider copper electrodes. The heat of vaporization of copper is $H = 1290$ cal/gm, and its density is 8·92 gm/cm³. Substituting these values in eq. (3) yields an erosion rate of 0·62 cm³/kA-sec. The 12,000-A test current wave has a kA-sec value of 0·11, so that the calculated volume of copper eroded is 0·068 cm³. From Fig. 2 the measured value is 0·17 cm³, i.e., 2·5 times larger.

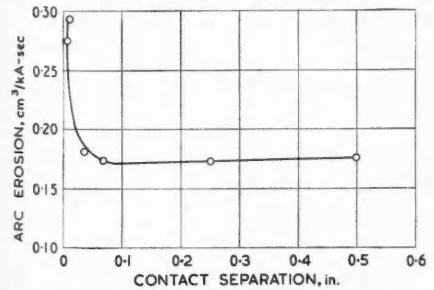


Fig. 5. **Arc erosion plotted against contact spacing for sintered silver-molybdenum alloy.**

This calculation considers only the amount of metal vaporized, and ignores the amount blown out in drops by the vapour as it escapes. Tests were run on some of the materials to estimate the liquid loss. An insulating cup was constructed around the arcing contact to catch most of the liquid drops. Many of these were quite large, measuring more than 1 mm in diameter. To permit easy escape of vapour, an inch of radial clearance was allowed between the walls of the cup and the contacts. The top extended about ½ in. above the upper contact surface. The total erosion rate was not altered significantly. The arrow-heads on Fig. 2 represent the volume of contact material vaporized, as estimated by subtracting the weight of the drops collected from the total loss. The vaporization loss, as estimated by test, then agrees very well with that from eq. (3).

*Performance of the Elements :—*

For copper, it is seen that the total erosion loss is quite closely represented by the sum of the estimated loss by vaporization and the loss of liquid in the form of drops blown out as this vapour escapes. Furthermore, the liquid loss constitutes a fairly high portion of the total loss. Except for carbon, tungsten, and possibly zinc, conditions with the remainder of the elements appear to be similar, in that in each case the total loss of material is greater than that which can be vaporized by the electric energy available. With each of the elements checked, the liquid loss has been substantial and in agreement with this approximate picture.

Only with carbon and tungsten does the calculated vaporization loss exceed the measured loss (Fig. 2). The discrepancies found appear to indicate the element of error in the vaporization equation itself. Tests with tungsten showed no detectable loss as liquid. It is difficult to make such an evaluation with carbon.

Consideration of these factors together with the melting temperatures of the elements reveals a general pattern. The amount by which the test erosion rate exceeds the estimated vaporization rate is an indication of the amount of material lost in liquid form. As would be expected, this difference tends to increase as the melting temperature decreases. With tin, the entire ¼-in. depth of the contact button turns to liquid during a half-cycle arc. Liquid loss is high. With tungsten and carbon, very little material is melted, and liquid loss appears to be negligible. It is interesting to note that the order of increasing arc erosion, decreasing volumetric heat of vaporization, and decreasing melting temperature is very nearly the same for the elements tested. Aluminium has a low melting point and a high boiling point, which would tend to maximize liquid loss ; also, it has a high specific heat of vaporization, which would tend to reduce vapour losses. This appears to be the explanation of the very high liquid loss indicated for this material. Zinc is the major exception to this trend of increasing liquid loss with decreasing melting temperature, in that loss by liquid apparently is a small factor in comparison with vaporization. The physical properties of zinc are consistent with this action in that zinc has by far the lowest of all of the boiling points and the lowest of the specific heats of vaporization, tending to maximize the vapour losses. It has the smallest difference between the melting and boiling temperatures, tending to minimize liquid effects. The order of excellence of the elements and the magnitude of erosion losses seem therefore to fall into position very well on the basis of the physical constants controlling vaporization and melting.

The possibility that a large portion of the erosion might be caused by oxidation of the surface in air should be discussed. At low current, this is an important mechanism[5] and explains the superior performance of silver in comparison with copper. However, this mechanism neglects the evidence that the erosion is controlled by phenomena at the contact surfaces and that, at high currents, the streams of metal vapour carry essentially all the oxygen far away from those surfaces. For aluminium, with its extreme affinity for oxygen, it is quite possible that the actual liquid loss is greater than that measured and is more nearly what is indicated by the difference between the measured erosion rate and the vaporization rate. Some of the liquid drops probably oxidize and are carried away as a gas.

*Sintered Materials :—*

One of the most striking facts concerning sintered contacts is that mixtures of two elements (such as silver and molybdenum in Fig. 3) can exhibit lower erosion rates than either of the elements by themselves. A parallel physical concept is that, for an alloy, the melting temperature, boiling temperature, and apparently the heat of vaporization each can be greater than the corresponding values for any of the components of the alloy. Furthermore, the liquid loss from the higher melting-point refractory component will be affected by the presence of the lower melting-point conducting component.

The correct nominal composition of a contact does not ensure that its arc erosion will be acceptable. Copper-tungsten contacts of the 30%-70% type, which were supposedly of equal quality, have been tested and found to vary in arc-erosion rate from near the tungsten value to near the copper value. One of the defects that might cause this poor performance is that of a poor bond in the tungsten matrix. If the contact were held together by the copper only, the melting of this material at relatively low temperatures would permit the tungsten particles to flow away with the liquid copper.

## Additional Factors

*Contact Spacing :—*

Fig. 5 shows that contact erosion increases at very small contact gaps. Two factors appear to combine to cause this. First, the restricted space between electrodes means that gas pressure and vapour velocity will be increased, tending to blow off more contact material. Second, because of the small spacing in relation to contact width, the fraction of heat which can flow from the cathode and anode drop region into the column, and escape without causing vaporization, is diminished.

The fact that erosion losses tend to remain relatively constant as contact gap (and total arc voltage) are increased beyong $\frac{1}{32}$ in. is powerful evidence that the erosion losses depend on electrical energy input at the surface and not on total arc energy. Further verification that erosion rates are reasonably constant at the higher spacings is given in the following.

*Current Magnitude :—*

According to the vaporization-rate equation, contact erosion should be proportional to current magnitude in the high-current range. A limited amount of erosion data was taken, ranging from 3000 to 25,000 A, 60 cycles. The same type of $\frac{1}{2}$-in. diameter contacts was used as in the one half-cycle tests, but with 2-in. spacing. Current durations in these tests were several times longer than in the half-cycle tests. Under these conditions, the correlation between the vaporization rates and measured erosion values appears satisfactory. Additional verification of the approximate direct proportionality between erosion loss and current magnitude may be found in a recent paper by Spayth and Heil.[6]

*Polarity :—*

This investigation was aimed at a.c. application, but some interesting polarity effects were noted. As would be expected from low-current experience the anode of the carbon arc lost much more material (about 80%) than the cathode (about 20%). However, with silver, the polarity had no appreciable effect. Whichever contact was on top experienced about 60% of the total loss. The explanation seems to be simply that melted material falls from the top contact and lands on the bottom one. With copper, the falling-material effect is present in addition to a polarity effect, so that the anode losses average about 65% of the total.

A large growth often appears on the copper anode with startling speed. At 0·2-in. spacing, during one half-cycle of arc, the anode surface melts, material gathers apparently at the anode spot, and a blunt column rises nearly to the opposite side. It does not matter whether the anode is on the top or bottom.

The same general phenomenon, but with the protuberance bridging a much smaller part of the gap, occurs at the tungsten anode. It is not seen with aluminium. The high electrostatic force caused by the anode-voltage drop, and the electromagnetic pinch-effect probably contribute to the formation of the column.

Statistical variations are much greater if the losses of each electrode are considered separately. For example, in one series of tests, the loss from a tungsten cathode was zero to three significant places. The anode loss alone was sufficient to give a fairly normal erosion rate for the pair. With some of the materials, the relative erosion rates for anode and cathode shift with spacing, in a manner which at present appears to be random.

## Comparison with Low Currents

It is interesting to compare high-current arcing-life relationships with those found in a previous investigation[7] reported by the author for the 10-A range. Except for the vast difference in magnitude, the primary difference is that life is inversely proportional roughly to the first power of arc current and of arc charge transfer at high current ; however, at low current, life was found to be inversely proportional to the 3·7 power of arc current and of arc charge transfer. This is partly because the microscopic pits which defined the termination of life with the minute arcs are of little consequence at high current. As a result, the great detrimental effect of slight bouncing at the break of circuit found at low current would not appear at high current, even if arcing durations were similar. Reduction in life due to bouncing can be estimated simply by adding the charge transfer occurring during the bounce to the value inserted in the rate equation.

In both ranges the contact surfaces approach planes as the end result of arcing. The effect of crowned or radiused surfaces on life at high currents is simpler than in the low-current range, because this flattening generally occurs during the first arc. Erosion was not consistently different on this first arc, although there was a tendency for it to be less. This is consistent with the reduction in loss found when contact spacing is increased.

The lack of dependence of arc erosion on line voltage, except insofar as it affects arcing current, appears to hold in both ranges.

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# Determination of Correct Baking Procedures for Enamelled Wires

By L. Kolár. (From *Elektrotechnický Obzor*, Vol. 44, No. 4, 1955, pp. 181-186, 10 illustrations.)

Investigations into satisfactory baking procedures are of great importance to manufacturers of enamelled wires, as they are often obliged to make changes in the lacquer composition. The degree of baking depends upon two main factors, i.e., the baking temperature $\theta$ and the baking time $t$ of the wire in the oven. The choice of $\theta$ is determined by the wire diameter $d$, the thickness of the enamel layer, the composition and viscosity of the enamel, the wire speed $v$, the length of the baking channel $l$ in the enamelling oven, the oven design, and other parameters.

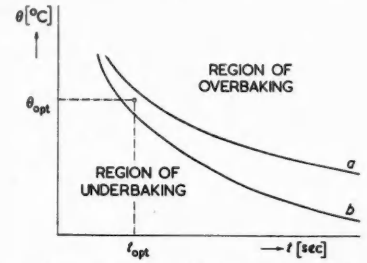



Fig. 1. **Baking temperature $\theta$ as a function of baking time $t$.**

For a given set of parameters the baking temperature $\theta$ and baking time $t$ are interdependent, as shown in Fig. 1, and for satisfactory results operating points must fall within the range limited by curves ($a$) and ($b$). Wire speed and the corresponding baking time are chosen in accordance with wire diameter and, for reasons of economy, high baking temperatures are preferable. Curves ($a$) and ($b$) indicate that, in the case of high values of $\theta$, accurate adherence to this temperature is required to produce good-quality products.

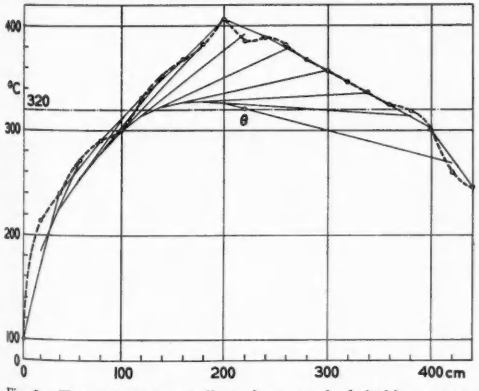



Fig. 2. **Temperature gradient in a typical baking oven, with the thermostat set to 320° C.**

Fig. 2 shows a typical temperature gradient in a baking oven, temperature being plotted as a function of position in the baking channel. The solvent is evaporated in that part of the channel where the temperature is rising; the lacquer polymerizes around the peak section of the curve, while cooling takes place in the final section of the channel. If the temperature increase is too rapid, cracks may appear in the enamel film; on the other hand, unduly rapid cooling is likely to cause radial stresses in the enamel.

In the following, the baking temperature $\theta$ is taken as the mean oven temperature, which in most cases is close to the setting of the thermostat. Optimum values of $\theta$ and $t$ are selected for each wire diameter. To permit comparisons to be made for wires of different diameter, a parameter $S$, indicating the degree of baking, is introduced, in which

$$S = \theta t \ [^\circ\text{C sec}]$$

It is assumed that, in a given oven, the quality of the enamelled wire remains constant over fairly wide variations of $\theta$ and $t$, provided that $S$ remains constant. The optimum degree of baking usually increases with wire diameter. As already mentioned, high baking temperatures are selected, i.e., between 350 and 425° C. Curves of the degree of baking $S$ as a function of wire diameter $d$, for various baking ovens, show that $S$ increases more or less in proportion with $d$, thereby enabling a rapid estimate of the correct degree of baking to be made.

## Determination of the Correct Degree of Baking

For this purpose samples of enamelled wire are prepared and, as $S$ increases approximately in proportion with $d$, it is usually sufficient to consider three or four wires of equally increasing size. Three to four samples of each wire size are therefore baked to varying degrees and are subjected to tests, as follows :—

(1) *Determination of Dielectric Constant* :—By measuring the dimensions of the sample and its capacitance, the dielectric constant can be calculated. With conventional lacquers this constant varies between 2·9 and 3·4 and, the better the baking, the smaller should be this value.

(2) *Resilience of the Enamel during Reeling* :—The sample is wound on a reel, in accordance with Czech standards, and the insulation resistance $R$ [megohms] and power factor tan $\delta$ [%] are measured in a mercury bath before and after reeling. Any variations in dielectric properties, including improvement, point to unsatisfactory baking.

(3) *Thermal Shock* :—Ten turns of the wire are wound under tension on a spool, the diameter of which is twice that of the wire. The sample is immersed for one minute in Wood's metal at a temperature of 125° C, the dielectric properties of the sample being measured before and after immersion. As before, any variations in these properties point to incorrect baking, while actual deterioration of the lacquer itself indicates its thermal unreliability.

(4) *Mechanical and Electrical Properties under Torsion* :—This test, which is intended for the combined determination of mechanical and electrical properties under torsion, is carried out by means of a special instrument incorporating a mercury-filled electrode, 10 cm of the wire being immersed in the mercury. The uninsulated ends of the wire are attached to the torsion heads, completing the electrical circuit *via* the body of the instrument. The power source is 10 V, 1000 cps, for the measurement of power factor tan $\delta$, while insulation resistance $R$ is measured with an ohmmeter. The rotating torsion head carries a revolution counter, and the number of revolutions at which short-circuiting occurs is noted. The actual short-circuiting is indicated by the lighting up of a test lamp in series with the measuring circuit.

Power factor tan $\delta$, capacitance $C$, and insulation resistance $R$ are measured during torsion. Fig. 3 shows plots of tan $\delta$ and $R$ against the number of torsion-head revolutions $n$ for two samples. Well-baked wires have

TABLE I

| | 1 | | | 2 | | | 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| *Baking data :—* | | | | | | | | | |
| $v$ [m/min] | 6·5 | | | 6·3 | | | 19·7 | | |
| $t$ [sec] | 18·5 | | | 19·1 | | | 13·7 | | |
| $\theta$ [°C] | 240 | | | 240 | | | 330 | | |
| $S$ [°C sec] | 4440 | | | 4580 | | | 4520 | | |
| *Wire dimensions :—* | | | | | | | | | |
| Overall diameter [mm] | 0·541 | | | 0·542 | | | 0·535 | | |
| Diameter of copper [mm] | 0·495 | | | 0·494 | | | 0·500 | | |
| | No. of Samples | tan $\delta$ [%] | $R$ [$10^5$MΩ] | No. of Samples | tan $\delta$ [%] | $R$ [$10^5$MΩ] | No. of Samples | tan $\delta$ [%] | $R$ [$10^5$MΩ] |
| *Reeling Test :—* | | | | | | | | | |
| Before testing | 10 | 3·40 | 1·16 | 10 | 4·95 | 0·45 | 10 | 1·87 | 2·7 |
| After testing | 9 | 2·94 | 0·35 | 9 | 2·39 | 1·16 | 7 | 1·97 | 1·7 |
| *Thermal Shock :—* | | | | | | | | | |
| Before testing | 10 | 3·93 | 5·94 | 10 | 2·70 | 13·55 | 10 | 1·87 | 870 |
| After testing | 10 | 2·20 | 15·70 | 7 | 2·84 | 5·30 | 10 | 2·45 | 283 |
| *Torsion Test :—* | | | | | | | | | |
| Before testing | 10 | 5·93 | 4·53 | 10 | 13·7 | 0·11 | 6 | 2·35 | 27·0 |
| After 5 revolutions | 10 | 6·74 | 1·80 | 10 | 14·4 | 0·08 | 6 | 3·14 | 10·7 |
| After 45 revolutions for wires in column (1) and 55 revolutions for wires in columns (2) and (3) | 6 | 7·90 | 0·64 | 6 | 13·4 | 1·19 | 3 | 3·60 | 4·0 |
| Average number of revolutions to cause short-circuiting | 49·1 | | | 58·3 | | | 60·0 | | |
| Average dielectric constant $\varepsilon$ before testing | 4·95 | | | 7·64 | | | 3·44 | | |

high values of $R$ and $n$, and low values of tan $\delta$ and dielectric constant $\varepsilon$. These curves are typical for the molecular structure of the enamel.

It is of interest to show how practical test results have helped in the improvement of baking procedures.

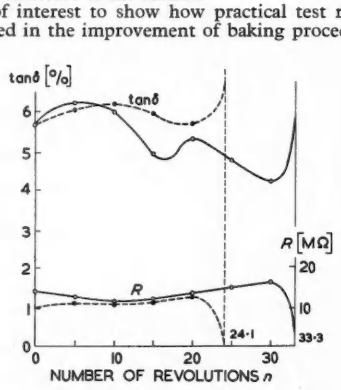



Fig. 3. **Average values of power factor tan $\delta$ and insulation resistance $R$ in torsion tests, for Araldite on wire of 1 mm diameter, with a baking temperature of 280° C.**

Full lines :— $v$ = 4·8 m/min, $t$ = 37·5 sec, and $S$ = 10,500.
Dotted lines :—$v$ = 4·5 m/min, $t$ = 40·0 sec, and $S$ = 11,200.

In this connection, Table I gives the average test results for three types of enamelled wires. Columns (1) and (2) contain data for experimental wires baked to two different degrees in one oven, while column (3) contains data of conventional wire products baked in another oven. For the interpretation of results, variations in resistance are first considered and, if these are not significant, then variations in power factor are taken into account.

Reeling tests indicate that only wires in column (3) are satisfactorily baked. Thermal-shock tests show that wires in column (3) are sufficiently stable thermally, as are those in column (2). In the case of wires in column (1), however, the values of tan $\delta$ indicate that these are not sufficiently baked. The torsion tests also indicate the satisfactory quality of the wires in column (3). It is surprising to note that, despite the good mechanical properties of the enamel of wires in column (2), the power-factor values obtained in the torsion test are very unsatisfactory. These high tan $\delta$ values are ascribed to moisture absorption by the polyamide lacquer prior to testing and are not considered representative of this enamel.

As a result of these tests, the wires in columns (1) and (2) have been given an increased degree of baking $S$ of slightly more than 4% ($\theta$ = 270° C, $t$ = 17·2 sec), and the products thus obtained have been found to be satisfactory.

# Applications of Arc-Cast Molybdenum

By N. L. Deuble. (From *Metal Progress*, Vol. 68, No. 2, August 1955, pp. 77-79, 3 illustrations.)

Arc-cast molybdenum does not as a rule compete with the powder-metallurgy product. Except for a few heavier sections used in the glass-melting industry, powder-metallurgy molybdenum is generally used for small items, such as electronic-tube parts, contacts, heating elements, spot-welding tips, and metallizing rods. Arc-cast molybdenum is more satisfactory for larger parts or for applications where lower gas content or superior weldability and machinability is needed. Furthermore, molybdenum-base alloys unsuitable for powder-metallurgy production can be readily arc-cast.

## Present Applications

*Magnetron Tubes* :—Unalloyed arc-cast molybdenum has been adopted by one large electronics company for relatively heavy parts of high-power magnetrons. Because the arc-cast molybdenum contains less gas, the tubes can be evacuated to the desired pressure in a much shorter time than can tubes made of powder-metallurgy molybdenum. In addition, longer shelf life is reported. With proper machining procedures arc-cast molybdenum is also superior in machinability; as an example, threaded sections have a much cleaner surface than with powder-metallurgy molybdenum. Finally, scrap resulting from cracks on some of the parts machined from arc-cast molybdenum now runs about 5%, as compared with 20% for the same part made from the powder-metallurgy product.

*Glass-Melting Furnaces* :—The glass industry has become a major user of large parts of both arc-cast and powder-metallurgy molybdenum. Its high melting point, high strength at elevated temperatures, good electrical conductivity, resistance to attack by molten glass, and the fact that the small amount of oxide formed is colourless are important advantages. Surface protection against oxidation is necessary, however, during start-up and for any parts not completely covered by the molten glass. Stirrers and other furnace parts are made from molybdenum, but the principal use is for electrodes, which weigh from 20 to 50 lb and may be either of the plate or rod type.

The first significant use of molybdenum electrodes was in 1940, and they are now used by at least twenty-five glass plants. Electric melting of glass gives increased production, improved quality, and longer refractory life, and molybdenum has shown itself to be the best electrode material at present available.

## Current Development Work

Experimental work to utilize the exceedingly high strength of molybdenum at elevated temperature is going forward. Notable among the potential applications are piercer points, die-casting dies, ramjet nozzles, and gas-turbine parts.

*Piercer Points* :—Molybdenum-base alloys are showing promise for piercer points to produce stainless- and alloy-steel seamless tubing, provided they are properly handled. Some comparative tests were made on the piercing of A.I.S.I. 4615 steel,* using a molybdenum alloy with 2% tungsten. Ordinarily, a regular alloy-steel piercer point is quenched in water after each use; 10 to 12 points are used and rotated, so that a cooled point is available for each billet. A standard point will average about 20 tubes of A.I.S.I. 4615. When the 2%-tungsten molybdenum alloy was used, quenching changed the shape of the point to a sphere. Air cooling improved the results slightly but did not prolong the life sufficiently to make the use of molybdenum points economically sound. When cooling was eliminated, however, a single point of molybdenum-base alloy pierced 650 tubes before the pierced hole became too small for the plug on the re-rolling mill to enter the cavity for rolling. During this time the point lost approximately $\frac{1}{8}$ in. on the diameter by oxidation.

*Die-Casting Dies* :—It is almost impossible to produce thermal checks in molybdenum because of its low coefficient of expansion and high thermal conductivity. For this reason, molybdenum offers great possibilities as a die material for brass die-casting, where other metals and alloys have uneconomically short lives. Preliminary tests showed that unalloyed molybdenum did not check in 13,000 shots, whereas some ferrous alloys checked in 1000 shots, and the best die steel in 3000. Unalloyed molybdenum, however, was not satisfactory, because the impression flowed slightly. Additional development work is now under way on the 0·5% Ti and the 1% V alloys, which have greater hot-hardness. While it is possible that changes in die design may be needed with the molybdenum-base alloys, it appears probable that, by increasing die life and lowering the unit die cost, they will eventually make the die-casting of copper-base alloys competitive.

*Ramjet Nozzles* :—Two or three years ago, one aircraft manufacturer designed an experimental molybdenum ramjet nozzle assembly which weighed only about one-quarter as much as a similar ceramic nozzle. This project was finally abandoned because of welding difficulties, but not before coated specimens of molybdenum had been tested for 6 hours without failure. This represents a sizeable safety factor, since the actual service life is only 15 minutes. Good progress in welding molybdenum for structural purposes has since been made by various companies, so that this consideration should not be such a limiting factor in future.

*Gas-Turbine Parts* :—The greatest interest in molybdenum-base alloys is for gas-turbine parts, such as guide vanes and blades. With their exceedingly high rupture strength, high modulus of elasticity, low coefficient of expansion, high thermal conductivity, and toughness at elevated temperatures, molybdenum-base alloys satisfactorily fulfil most design requirements, except those of low density and oxidation resistance. The high density is not too serious because of the high strength and elastic modulus of the metal at service temperatures. The development of a wholly satisfactory oxidation-resistant coating offers a challenge to research; if this problem can be solved, the operating temperature of gas turbines could be increased by some 300 to 400° F.

## Future Applications

Moybdenum will undoubtedly find extensive and important new uses. The research and development carried out to-date have shown that arc-cast molybdenum and its alloys have inherent characteristics which make them exceedingly attractive to the designer of high-temperature equipment. Industrial utilization of these materials, however, is only in the initial stages. Additional work is needed on problems such as oxidation resistance and welding.

Potential applications outside the elevated-temperature field should be explored; the high modulus of elasticity and resistance to corrosion offer interesting possibilities. Research on new and improved molybdenum-base alloys is being continued. Industrial development programmes will not be hampered by shortages. The availability of arc-cast molybdenum and molybdenum-base alloys is limited only by present facilities, which can be readily expanded, if necessary.

* 0·13 - 0·18 C, 0·45 - 0·65 Mn, 0·20 - 0·35 Si, 1·65 - 2·00 Ni, 0·20 - 0·30 Mo.

# Report on Geneva (II)

*Following the first instalment in our September issue of our report on the International Conference on the Peaceful Uses of Atomic Energy, held at Geneva from August 8 to 20, 1955, this issue contains further descriptions of power reactors, and gives indications regarding capital investment required and the cost of electricity from nuclear power. In addition, various types of research reactors are summarized. Our final instalment next month will include the subject of radioisotopes.*

## POWER REACTORS (*Continued*)

### Aqueous Homogeneous Power Reactors

Although difficult problems remain to be solved, aqueous homogeneous reactors appear to be among the most promising for the economical production of nuclear power. Their attractiveness is attributable to the fluid state of the fuel and the unique quality of heavy water as a moderator. The main advantages deriving from these features are as follows :—

(1) Aqueous homogeneous reactors can be designed for high power density and low fuel inventory. The critical mass of fuel is low, and the rate at which heat can be removed from a reactor may be limited only by the rate at which the fuel can be circulated and the permissible temperature rise. Heat is removed from the fuel in equipment external to the reactor. The equipment can be designed for maximum performance without regard to neutron cross-section of materials or to the many other factors which must be considered when heat is extracted from the fuel in the reactor core.

(2) Reactor fuels can be purified continuously, to remove fission products and radiation-damage products. Fuel preparation, handling, and reprocessing are simplified, and high burn-up of fuel is achieved.

(3) These reactors possess a very high degree of nuclear stability. Gross changes in operating conditions can be obtained by adjusting the fuel concentration. The strong negative power coefficient provides regulation and prevents harmful power excursions. Control rods or plates are unnecessary.

(4) Simple mechanical design results from the use of a fluid fuel and moderator and the elimination of control elements. The reactor vessel can be a tank containing only those parts required to achieve the desired flow distribution and, in some designs, to separate the reactor into regions containing fissionable or fertile materials.

(5) The absence of structural materials in the reactor core, the use of heavy water as the moderator, and the continuous removal of fission-product poisons make it possible to minimize the parasitic absorption of neutrons.

The use of fluid fuels and an aqueous moderator also results in undesirable characteristics, which may be summarized as follows :—

(1) High pressures are associated with the high temperatures which are required for producing power efficiently. The vapour pressure of water is 1200 psi at 572° F and 2400 psi at 662° F. Circulating-fuel reactors are operated with added pressure to prevent cavitation in the pumps and to minimize the volume of gases produced by decomposition of the moderator.

(2) Large volumes of very highly radioactive materials are present in a fluid state at high temperature and high pressure. Provision must be made for containing these materials if they leak from the reactor vessels or piping. Pumps, piping, and heat exchangers become radioactive from contact with the fuel. Their replacement or repair can, of course, be difficult and expensive.

(3) Uranium, plutonium and thorium compounds, water, and materials of construction form complex physical and chemical systems. Limitations on operating conditions are imposed by the physical and chemical characteristics of the fuels and by corrosion and erosion effects.

(4) Deuterium and oxygen are produced by radiolytic decomposition of the moderator. They must be recombined safely.

Aqueous homogeneous reactors are classified as "one-region" or "two-region," according to the distribution of fissile and fertile materials in the reactor. They are "circulating-fuel" or boiling, depending upon the method of removing heat. In a one-region reactor the fissile and fertile materials are uniformly mixed. In a two-region reactor they are separated into a core of fissile material and a blanket of predominantly fertile material. In a circulating-fuel reactor the fluid fuel is circulated through the reactor and external heat-exchange equipment by natural or forced convection. Heat is removed from a boiling reactor by vaporizing coolant in the reactor and condensing the separated vapour in external heat exchangers.

In the United States most of the engineering effort has been devoted to the development of two-region circulating-fuel reactors, but their technology is equally applicable to one-region reactors.

Experience with the Homogeneous Reactor Experiment* has demonstrated that there are few uncertainties in the nucelar and process design of circulating-solution reactors. The Homogeneous Reactor Test, now being assembled in the building formerly occupied by the Homogeneous Reactor Experiment at the Oakridge National Laboratory, represents an advance over the latter in power, physical size, and quality of construction and is, in nearly all respects, a prototype of a full-scale nuclear power plant.

The objectives of the Homogeneous Reactor Test are to demonstrate that a homogeneous reactor of moderate size can be operated with the continuity required of a power plant; to establish the reliability of engineering materials and components of a size which can be adapted to full-scale power plants; to evaluate equipment modifications which will lead to simplifications and economy; to test simplified maintenance procedures and, in particular, maintenance under water; and to develop and test methods for the continuous removal of fission and corrosion contaminants.

Construction is scheduled for completion early in 1956. Following the usual mechanical and leak testing, the reactor will be put into operation with only heavy water in the blanket system; the fuel will be a dilute solution of uranyl sulphate (about 90% $U^{235}$) in heavy water. Operation will continue with this combination for a minimum of six months, to establish the reliability of operation and to test the effectiveness of continuous chemical extraction processes. For the latter purpose, a chemical pilot-plant is attached directly to the reactor. As a second phase of the reactor test programme, the blanket will consist of a suspension of thorium oxide in heavy water. Dependent upon the results of operation with $U^{235}$ under these conditions, $U^{233}$ may be substituted as the fuel for a final evaluation of the $U^{233}$-Th cycle.

The bases for the design of the reactor were intended to take the fullest advantage of the progress in chemistry, materials, and component development, and the experience with the first reactor experiment. The physical size of the reactor and its auxiliaries was increased appreciably beyond that of the first experiment. The size of the reactor core represents a compromise between two objectives, attainment of the high

* See *The Engineers' Digest*, August 1955, pp. 359-361.

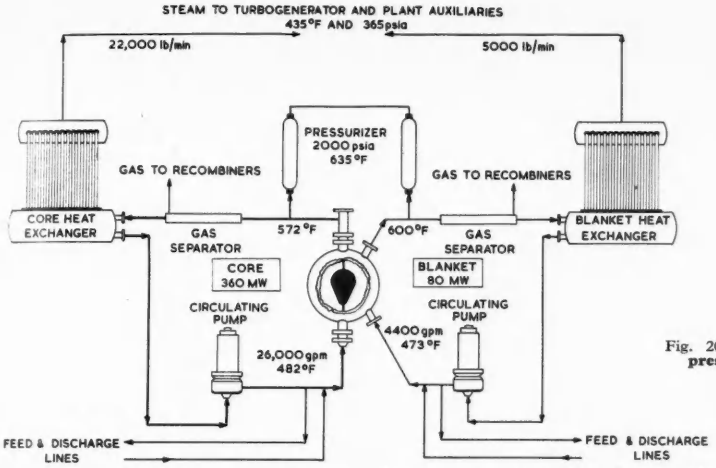



Fig. 20. **Flow diagram of high-pressure circulating system.**

specific power required for economy in a large plant, and evaluation of the fabrication and durability of a zirconium-alloy core tank. The power output was therefore set at 5000 kW (heat) with the possibility of a maximum of 10,000 kW, and the core diameter at 32 in. Although these together result in a low specific power of 17 kW per litre in the core at 5000 kW, this was considered acceptable, since operability at a relatively high specific power of 30 kW per litre had been demonstrated in the first experiment.

The increase in fuel temperature from 482° F in the first experiment to 572° F was based upon the favourable corrosion resistance of both stainless steel and Zircaloy-2 to dilute uranyl sulphate and the higher temperature at which the two-liquid phase region appears in the more dilute fuel. The design pressure of 2000 psi resulted from the necessity for an overpressure on the system, to prevent boiling with consequent cavitation in the pump and to reduce the volume of gas in the core.

The vortex-type flow through the core of the first experiment was abandoned in favour of a straight-through flow, because hydrodynamic experiments demonstrated the pressure drop of the former to be excessive for larger cores. As a result, the extraction of radiolytic gas directly from the core was excluded, and external gas separation in the exit pipe from the core was specified.

As in the first experiment, the separated radiolytic gas was to be recombined at low pressure, but by means of a platinized alumina catalyst instead of combustion in a flame-type recombiner. To dispose of the fission product gases stripped from the fuel by the radiolytic gas, adsorption and subsequent decay on beds of activated carbon were specified.

Type 347 stainless steel was designated as the material of construction, except for the Zircaloy-2 core vessel and titanium at points of high turbulence, such as the pump impellers and the gas separator.

The control of the reactor is to depend entirely on solution concentration for shimming and on the temperature coefficient for safety.

*American Conception of a* 100-*MW Homogeneous-Reactor Power Station* :—

A nuclear power station capable of producing 100 MW of electricity appears to be of convenient size to form the basis for a two-region circulating-fuel reactor. Such a station would be separated into three plants, i.e., the reactor plant, the generating plant, and the chemical plant where the fuels are processed.

The reactor plant is subdivided into three systems or groups of equipment, these being the high-pressure circulating system, the recombiner system, and the low-pressure storage and waste-disposal system. In two-region reactors, each system would have separate sets of equipment for handling core and blanket fluids.

A flow diagram of the high-pressure circulating system is shown in Fig. 20. The uranyl sulphate solution, containing 8·6 grams of uranium per kg of heavy water, is pumped through the core circuit. A thorium oxide slurry, containing 1130 grams of thorium per kg of heavy water or 1000 grams per litre of slurry, is circulated through the blanket equipment. Gas is removed from the fuels in the separators and sent to recombiner systems, where heavy water is regenerated and returned to the high-pressure circulating systems. Heat is extracted in the exchangers to form steam, which is used in the generating plant and in some reactor auxiliaries. Pressurizers are provided for both the core and the blanket and are interconnected to aid in preventing the pressure differences between the two systems from becoming large enough to damage the zirconium tank.

The reactor vessel may be of the " straight-through " or of the " concentric inlet and outlet " core type. The latter type, illustrated in Fig. 21, appears to have an advantage in mechanical simplicity. There are fewer problems arising from the difference in coefficients of expansion of Zircaloy, from which the core tank is made, and the material used for the pressure vessel, i.e., carbon steel clad with stainless steel. It is doubtful whether a satisfactory pressure vessel can be constructed of stainless steel in the near future, except at a prohibitive cost.

It is estimated that 30 lb/min of deuterium and 120 lb/min of oxygen will be produced in the core of the reactor by radiolytic decomposition of the moderator. This corresponds to the production of 160 cu ft/min of gas saturated with water vapour at 572° F and 2000 psi, and to 2% by volume of gas in the fluid leaving the reactor core. Gas production in the blanket is estimated to be one-tenth that in the core. Special axial-flow gas separators have been developed for removing these gases.

The development of satisfactory circulating pumps is one of the major problems of aqueous homogeneous reactors. The pumps must be completely leak-tight and must operate for long periods without maintenance. Furthermore, internal parts must be easy to remove when replacement or repair becomes necessary.

Fig. 22 shows the design features of a canned rotor pump. Similar pumps have been built to circulate 4000 gpm of water against a 250-ft head at 2000 psi.

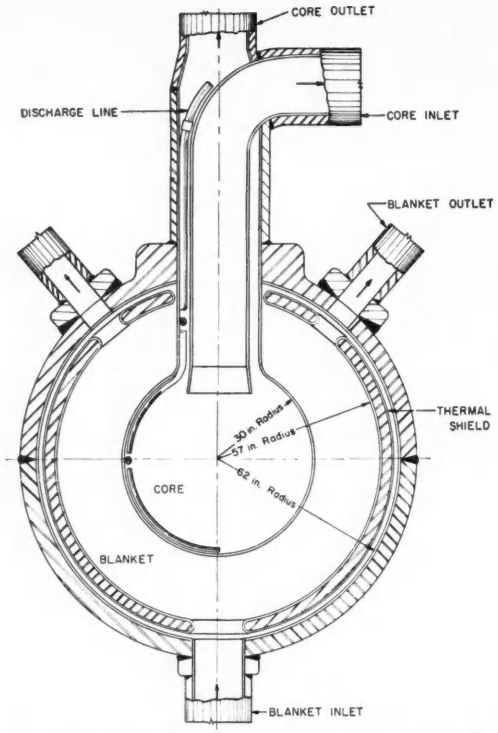



Fig. 21. **Two-region aqueous homogeneous reactor with "concentric inlet and outlet" core.**

Others are being designed for pumping 16,000 gpm under similar head and pressure conditions. There is little doubt that a unit can be built to pump the full 26,000 gpm core flow. Stainless steel is a satisfactory material for most of the pump parts which will be in contact with the fuels. Titanium should be used for the impeller, for the labyrinth seals, and for reinforcing parts of the casing. Hydrostatic bearings or bearings with Stellite running on Graphitar may be used. Maintenance is simplified by making all internal parts removable through a flanged opening at the top of the pump. Condensate injected into the rotor cavity will keep the fuels out of the bearings and reduce the radiation level inside the motor.

Two types of systems have been designed for recombing the deuterium and oxygen produced in these reactors. One requires a flame recombiner in which a combustible mixture of the gases is burned. In the other the gases are diluted below the combustible limit and are recombined on a platinum or a palladium catalyst. The hazards of handling explosive mixtures containing radioactive contaminants have made it seem prudent to limit flame recombiners to operation at low pressure. Catalytic recombiners have been designed for operation at both low and high pressures.

As in the Homogeneous Reactor Test, control of the reactor will rely entirely on variable fuel concentration and the negative temperature coefficient of reactivity.

The reactor will be started by an orderly charging of the fuel into the core and blanket systems. The slurry will be pumped directly from the storage tanks into the blanket circulating system. At the same time, heavy water will be evaporated from the core solution in the tanks and pumped into the core circulating system. When both the core and blanket systems are filled, they will be pressurized and the circulation will be started. At this point it will be desirable to heat the circulating liquids to about 400° F by injecting steam into the heat exchangers. Then, concentrated fuel will be added at a controlled rate. When the critical concentration is reached, the chain reaction will begin and the reactor temperature will rise with continued addition of fuel. When the temperature approaches the specified operating temperature, steam will be extracted from the heat exchangers to start the turbine. Final adjustments will be made to the concentration with the turbo-generator plant operating at full output. Excess fluid resulting from the expansion of the liquid in the reactor will be discharged to the storage tanks.

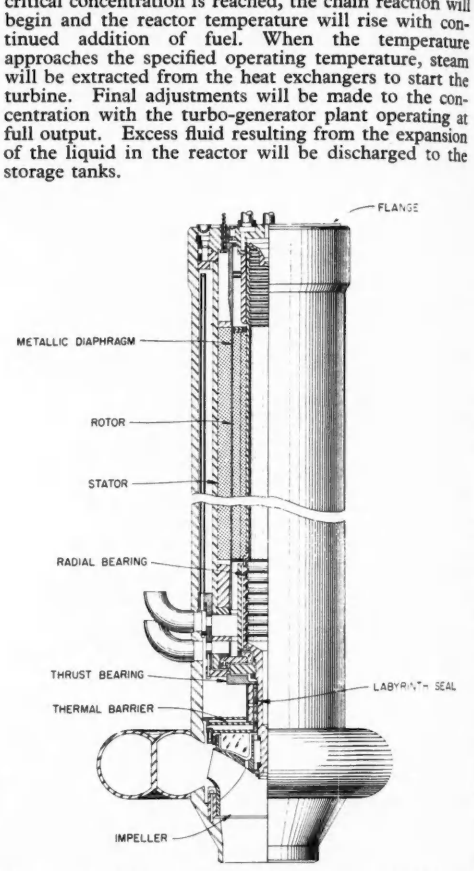



Fig. 22. **Circulating fuel pump for aqueous homogeneous reactors.**

The process will be reversed in a normal shut-down of the reactor. Fuel from the core will be discharged to the dump tanks, where the heavy water will be distilled and returned to the reactor. In this way the operating temperature can be reduced slowly until the reactor is cool. In an emergency the reactor fluids can be discharged rapidly into the storage tanks.

As has already been mentioned, circulating-fuel homogeneous reactors have a number of disadvantages. For instance, they demand the use of absolutely reliable pumps, the repair of which must be carried out by remote control. Furthermore, the power obtained from one kilogram of fissionable material is not high, since a considerable part of the uranium load fills up the circulation circuit and the heat exchangers and thus does not participate in the reaction. Also, when the heat exchangers are heated by a medium with neutron activity, radioactive steam is supplied to the turbines, causing great inconvenience in operation. To overcome these difficulties to a great extent, Russian effort is directed towards the development of boiling homogeneous reactors. In the U.S.A., experience with this type of reactor is limited to a few experiments with the Los Alamos Water Boiler.

*Russian Proposal for a Boiling Homogeneous Nuclear Power Reactor :—*

In this reactor, the moderator is natural or heavy water, and the fuel is either pure fissionable material, enriched uranium, or natural uranium. In the last case, only heavy water may be used. Uranium may be distributed in the moderator in the form of a salt solution or as a suspension of oxide powder ($U_3O_8$). The reflector, for fuel breeding, is filled with heavy water carrying thorium, as $ThO_2$, in suspension.

The design of such a plant requires the solution of a number of physical and engineering problems, such as the behaviour of suspensions under various operating conditions, the purification of steam as it emerges from the reactor, and circulation problems.

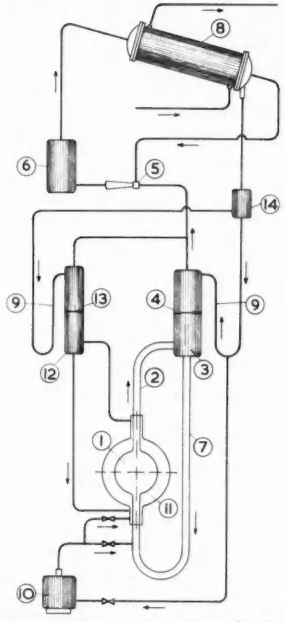



Fig. 23. **Diagrammatic arrangement of Russian boiling homogeneous reactor with fuel regeneration.**

A diagram of a possible plant for a boiling homogeneous reactor with fuel breeding is given in Fig. 23, in which it will be seen that the steam passes from the reactor (1) through a riser (2) into the separation vessel (3) in which steam is separated from the water. The steam is then directed to a purifying apparatus (4), to the injector (5), and the catalytic chamber (6). The water from the separation vessel returns to the reactor *via* the downcomer (7). Circulation of the medium is maintained by the difference in the density of the steam-water mixture in the reactor and the riser and the density of the liquid in the downcomer.

Steam from the chamber (6) enters the heat exchanger (8), which produces the secondary steam for the turbines. The injector (5) circulates part of the steam through the heat exchanger and catalytic chamber in order to recombine the remainder of the detonating gas. The condensate returns from the heat exchanger to the reactor. An electric boiler (10) serves to maintain the suspensions when the reactor is started up.

The reactor is surrounded by a reflector (11) which is filled with a boiling suspension of thorium in heavy water and equipped with an external circulation system. The steam formed in the reflector is separated from the liquid in a separator (12), purified in apparatus (13), and then joins the steam flowing from the reactor to the catalytic chamber (6). The condensate from the heat exchanger enters a tank (14), whence it is redistributed between reactor and reflector, (9) being a liquid seal.

Calculations have made it possible to establish the dependence of the thermal power of the reactor upon the pressure for various concentrations of fissionable material in the core. Thus, it was found that, for a constant uranium concentration in the core, each pressure corresponds to a definite reactor power, i.e., in the case of constant heat consumption in the external circuit, the boiling reactor is stable in operation. However, control devices are necessary to vary the reactor power while maintaining the operating pressure, or to vary pressure while maintaining power at a constant level. A convenient control device may be in the form of a choke in the downcomer of the circulation circuit, since it has been established that a reduction in circulation results in a reduction in reactor power.

## Fast Power Reactors

How long uranium and thorium supplies will support a nuclear power industry depends not only on the amount available from the earth's surface but also upon the efficiency of its utilization. To increase the utilization of the raw material must always be a prime objective of the nuclear-energy technologist, just as it has been a traditional objective of designers of coal-fired electrical generating plant. It may be acceptable in the early development of the industry to place as the first goal reactor power plants which are competitive with coal-fired plants in an economic sense. Success in this inevitably will bring a demand for an increased utilization of the nuclear raw material.

The fundamental difference between thermal and fast reactors is in the average energy of the neutrons at the time of absorption, this energy being higher in fast reactors. The basic reason for their development is the possibility of much more efficient utilization of the uranium fuel. The energy content of $U^{238}$ is little different from that of $U^{235}$ but, when natural uranium is fed into a thermal system, all but a few per cent, depleted in its content of $U^{235}$, must be thrown onto the ash heap. Therefore, the possibility afforded by the fast reactor of using almost all the uranium should be most attractive.

Electrical power from a fast reactor, the Experimental Breeder (EBR), was produced in the U.S.A. as long ago as December 1951. The second Experimental Breeder Reactor (EBR-II), with a power rating of 60 MW (heat), is now in the engineering design and development stage. Its construction is scheduled to begin in 1956 and is expected to be in operation in 1958. In Britain, an experimental fast reactor of similar capacity is being built at Dounreay. Both these plants will be described in the following.

*The EBR-II Fast-Neutron Reactor Power Plant :—*

The primary purpose of the EBR-II is to demonstrate the engineering feasibility of a fast power reactor system which will be economically competitive with existing power sources. It is not expected to produce electricity at a competitive price, but should demonstrate the engineering feasibility of a reactor system which, when scaled up to central station size, will be competitive.

The plant is divided into four major systems, which may be defined as follows :—(1) The primary system ; (2) the secondary system ; (3) the steam system ; and (4) the fuel process system.

The primary system is contained in a single vessel. All components, including the reactor, the primary sodium pumps and piping, the heat exchanger, and the fuel transfer and storage system, are submerged in sodium, as shown in Fig. 24. The reactor consists of an enriched core of uranium-plutonium alloy, in the approximate shape of a hollow cylinder, surrounded on all sides by a uranium-breeding blanket. The fuel and

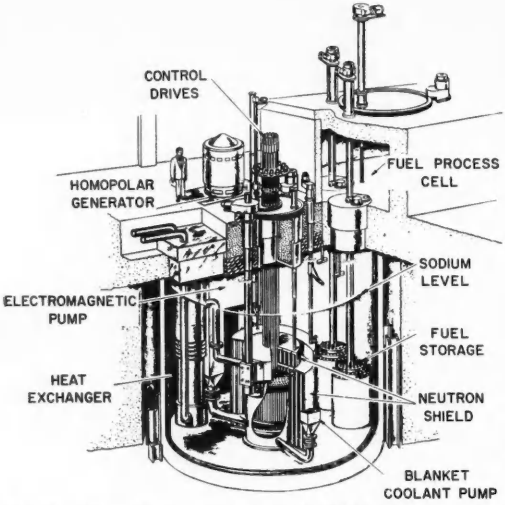



Fig. 24. **The primary system of the EBR-II fast-neutron reactor power plant.**

blanket material are contained in sub-assemblies of hexagonal cross-section, positioned vertically in a closely packed array. The coolant enters the bottom of each sub-assembly, flows upwards through the sub-assembly, and then passes from the reactor through the intermediate heat exchanger.

The heat is transferred from the heat exchanger to the steam generator by the secondary sodium system. This system is non-radioactive and serves to isolate the radioactive sodium in the primary system from the steam generator, and also to isolate the reactor from the moderating effect of water. The steam generator is a sodium-to-water/steam heat exchanger, supplying steam at 850° F and 1250 psi to a conventional turbo-generator of 20,000 kW capacity.

The reactor assembly, a cross-section of which is shown in Fig. 25, consists of the reactor proper, the containing tank, and the surrounding neutron shield. The approximate overall diameter and height are 10 and 13 feet, respectively. The reactor is divided into

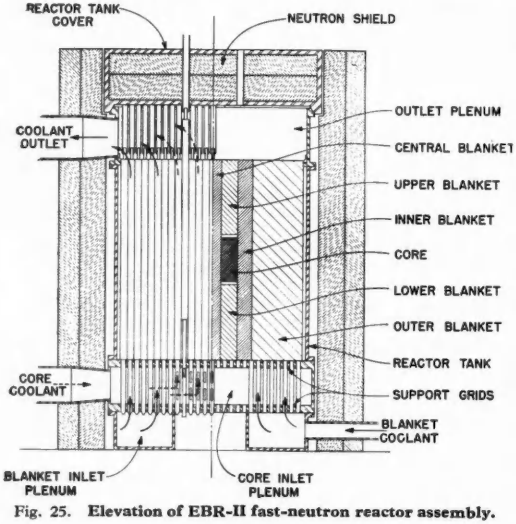



Fig. 25. **Elevation of EBR-II fast-neutron reactor assembly.**

four main zones, i.e., core, central blanket, inner blanket, and outer blanket. Each zone comprises a number of right hexagonal sub-assemblies containing the fuel or blanket elements.

Division of the annular blanket surrounding the core into two separate zones, the inner blanket and the outer blanket, is necessitated by the wide variation in power generation across this region and the desire to achieve everywhere the highest possible fraction of unit volume devoted to blanket material (uranium). In the blanket area immediately adjacent to the core, the unit volume fraction of uranium permissible is relatively low, since the power density is high and cooling is difficult. In the area near the outer periphery, however, the uranium fraction may be high, because the power density is low and cooling is more easily effected. The division of the blanket into two zones of differing unit volume fraction of uranium represents a practical compromise between an infinite number of such zones and a single zone of constant uranium fraction.

The control sub-assembly consists of a modified, movable-core sub-assembly contained in a guide thimble. The control rod has four sections, i.e., upper blanket, void (sodium), core, and lower blanket. Control is effected by movement of the core section into and out of the core (with simultaneous substitution of void section for core section). As indicated in Fig. 25, the reactor is contained in a tank which positions and supports the sub-assemblies, and directs the flow of coolant sodium.

The coolant flow direction is upwards through the reactor. Distribution of flow is accomplished by the orificing of each sub-assembly, identical orificing being used in all sub-assemblies in a given row (except in the special case of control sub-assemblies). In order to accommodate the very large range of flow rates required, two parallel flow systems, each with its own pump, are used. One system supplies the central blanket, core, control sub-assemblies, and the first sub-assembly row of the inner blanket. The other supplies the second sub-assembly row of the inner blanket and all the outer blanket. The two systems have separate inlet plenum chambers and a common outlet plenum chamber. Approximate total flow rate and average coolant temperature rise are 11,000 gpm and 130° F, respectively.

The primary coolant system includes the reactor, the intermediate heat exchanger, and the circulating pumps. A significant feature of this design is the close-coupled arrangement of the components of the primary system in the primary tank, in which they operate submerged in liquid sodium. Coolant is pumped directly from the bulk sodium in the primary tank to the two reactor inlet plenum chambers. After flowing upwards through the reactor into the common top plenum chamber, it passes through the intermediate heat exchanger and then returns to the primary tank. The flow through the reactor is monitored by electromagnetic flowmeters, provided with insulating jackets to permit submerged operation.

This design requires that the pump be located within the primary tank and that it be capable of operating submerged in sodium without any form of auxiliary cooling other than that provided by the passage of the liquid being pumped. A d.c. conduction-type electromagnetic pump is employed, with sufficient capacity to handle the pumping requirement of the main coolant system. The pump, shown in Fig. 26, has a capacity of 10,000 gpm at a head of 75 psi. The current of approximately 250,000 A required to drive the pump is supplied by a homopolar generator located near the top of the primary tank shield. This very large current requirement makes it necessary to place the pump and generator as closely together as possible. Consequently, the pump is located directly below the generator near the level of the sodium surface in the primary tank.

The current is carried from the generator downwards through the shield in sodium-filled ducts which attach to the pump housing. The ducts are partly filled with copper bars to provide adequate gamma shielding.

Sodium is employed in preference to sodium-potassium alloy as the working fluid of the secondary system, because of its superior heat-transfer characteristics, and to eliminate the possibility of contaminating the primary-system sodium with potassium in the event of leakage within the heat exchanger. An a.c. electromagnetic pump is employed, with a capacity of approximately 5000 gpm at a head of 25 psi. An expansion tank, with an inert-gas blanket to maintain the desired system pressure, is provided at the inlet to the pump. External heating provisions are installed on the piping, to assure maintenance of the sodium in the molten state under all conditions.

In the system, water enters the steam generator at 450° F and leaves as superheated steam at 850° F. The steam generator is of the "once-through" type, with integral preheating, evaporating, and superheating sections. Shell and tube construction is used, with the sodium on the shell side. The tubes are double-walled, with provision for detection of leakage into the annular space between the tubes during operation. Steam conditions at the turbine throttle are 1250 psi and 850° F, with a maximum flow rate of approximately 200,000 lb/hr. The turbine employed is an extracting, condensing, single-flow type of unit of 20,000 kW maximum capacity. Five steam-extraction points are employed to supply steam to five stages of feedwater heating.

It is desirable in a fast power reactor to recycle the fuel as rapidly and as economically as possible, to minimize the costs of fuel inventory and fuel processing. Because of the high specific activity of the fuel from the reactor, a long "cooling time" is required if the fuel is processed by present aqueous methods, and a large economic penalty results because of the large fuel inventory required for cooling.

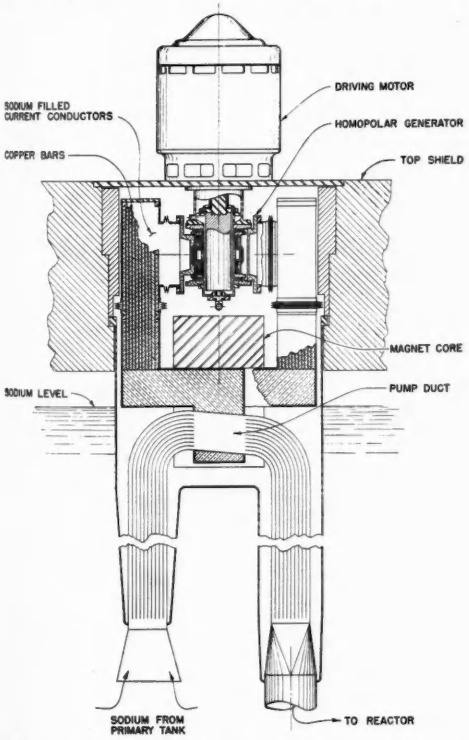



Fig. 26. **Electromagnetic pump and generator of primary system of EBR-II fast-neutron reactor plant.**

The EBR-II plant employs "pyrochemical" processing, which involves high-temperature slagging in the molten metal phase. The costly conversion steps required in aqueous systems are avoided, and the size and complexity of the equipment are reduced considerably. However, the process is not as efficient, and complete decontamination is not obtained. The results to-date indicate that more than 90% of the fission-product activity can be removed by the process. This is an acceptable decontamination for fast reactor operation, because it is relatively insensitive to fission-product poisoning. Sufficient residual fission-product activity remains in the fuel, however, to require shielded remote-control fabrication of the alloy. After processing, therefore, it is necessary to reconstitute and fabricate the material, and to assemble the fuel elements completely by remote-control methods.

Since EBR-II is fuelled with plutonium, semi-remote operation and complete containment would be required, even if complete fission-product decontamination were obtained. Therefore, the requirement of complete remote-control operation due to residual fission-product activity is not a large additional burden.

*The Dounreay Fast Reactor Project :—*

The fast reactor now being built at Dounreay by the United Kingdom Atomic Energy Authority is essentially an experimental project, since no engineering experience is available on which to design a core with the rating, outlet temperature, and burn-up required. The best way to obtain this knowledge seems to be to build a plant having the most flexible design that can be achieved. As failures are replaced by better components it is hoped to demonstrate that a fast reactor can be a sound economic proposition for the production of industrial power.

The plant will consist of a pot through which enough coolant can be pumped to remove more than 60 MW of heat. In this pot, tube plates and other structures can be placed to support the blanket and core of the reactor. If experience shows the first designs to be unsatisfactory, the contents of the pot can be removed and a fresh start made.

If high heat output is to be obtained, a coolant of high specific heat and high thermal conductivity is needed, because of the small core size, while a low vapour pressure is of great advantage. These considerations led to the choice of liquid sodium, with possibly some addition of potassium to lower the freezing point.

The reactor core will contain a substantial quantity of fissile material. It therefore represents an investment which must not be lost as the result of an accident. Because of the persistence of heat release after reactor shut-down, it is essential that a supply of coolant to the core is guaranteed at all times. The core of the fast reactor is so highly rated that it would quickly rise to melting point if the coolant were removed. The design of the cooling circuits has therefore been prepared with this in mind. It will be made from stainless steel throughout.

Twenty-four parallel loops, each comprising two separate heat-exchanger sections and an electromagnetic pump, will complete the primary circuit. The lower part of each loop will be jacketed with an outer tube, through which the secondary coolant will be pumped. Above this will be a short flattened section, against which are pressed the electromagnetic windings. At the top will be another jacketed heat-exchange section, providing thermo-syphonic rejection of shut-down heat to air in the event of total failure of electrical supplies. Twenty of the loops feed the core from a common header space at the top of the pot, while four more

provide coolant for the blanket. Multiple secondary and subsequent heat-rejection circuits will be provided. Even the power supplies will be separated. Electrical power for the pumps will be provided by diesel generators, each of which will be connected to only two of the primary pumps and their subsidiary circuits. Thus, the failure of one generator will cut out only one-tenth of the pumps

Sodium or sodium-potassium alloy will be used for the secondary coolant. On grounds of safety it is argued that the secondary coolant must be chemically inert to the primary coolant, thus ruling out water. The secondary coolant will carry the heat to a boiler house for steam raising. As there will be no radioactivity involved, a reaction between sodium and water in this part of the plant would not involve widespread hazard. Waste heat will be disposed of by a seawater-cooled condenser. The arrangement of the circuits is shown diagrammatically in Fig. 27.

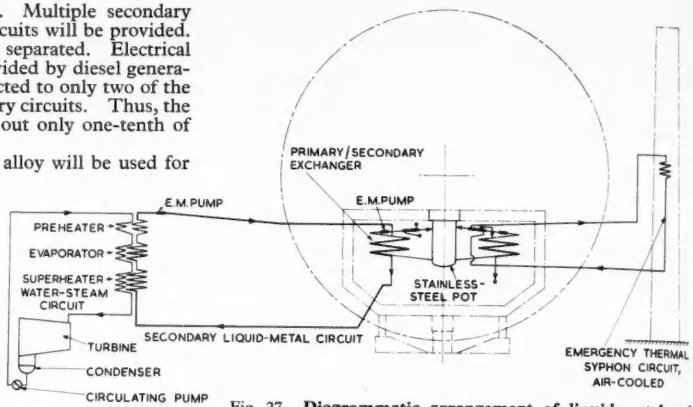



Fig. 27. **Diagrammatic arrangement of liquid-metal and steam circuits in the Dounreay fast reactor.**

The secondary coolant must not become radioactive, so that a neutron shield is needed between the pot and the heat exchangers. This shield consists of graphite stacked around the pot to a thickness of 4 ft. Most of the graphite will contain enough boron to absorb the neutrons when they have slowed down. The advantage which it is hoped will be gained by the use of borated graphite for absorbing neutrons is that very much less long-lived activity will be induced than if steel were used. This should simplify the problems of dismantling the neutron shield if ever it should be necessary. The graphite will be kept hot to reduce radiation damage.

The graphite and the pot will be supported on a steel structure standing on a concrete base, which forms part of the biological shielding. This will consist of a concrete bowl of almost 90 ft o.d., 45 ft high, with a minimum thickness of 5 ft. These dimensions are determined by the size of the heat exchangers and the activation of the coolant. The roof slab, which has a central hole 20 ft in diameter, will be supported on a ring of vertical columns. These introduce complications, because they will stand in the space to be occupied by heat-exchange equipment, but the slab is too large to be supported round its rim without introducing a prohibitive concentration of reinforcement near the centre. The heat exchangers will hang from the roof slab.

Pure sodium is a better heat-transfer medium than sodium-potassium alloy and is much cheaper, but, if it is to be used, the entire primary circuit must be kept above the freezing point of sodium. The whole of the vault will therefore be made into a hot-box, with air heaters. The concrete and the columns supporting the roof will be lagged and air-cooled. In the early stages of operation, sodium-potassium alloy will be used, so that the vault will be accessible when the activity of the coolant has died away after shut-down.

A theoretical examination of the problem of the safety of fast reactors has been made, and the magnitude of the explosion that would occur, if the reactivity were rapidly increased beyond prompt critical, has been estimated. It is doubtful whether a pressure vessel of practicable dimensions could contain such an explosion. It is confidently believed, however, that the danger can be eliminated by suitable design of the control system and of the core itself. Although an explosion will not occur, it cannot be stated definitely that there will be no sort of plant failure which could result in the escape of fission products. With something like a hundred million curies in the core, an escape of more than a few per cent would be a very substantial hazard over a wide area. The reactor will therefore be enclosed in a steel sphere, 135 ft in diameter and about 1 in. thick, to contain these fission products in the very improbable event of their escape from the core.

The liquid-metal coolant brings with it a risk of fire. To reduce this risk no significant quantity of water will be allowed inside the sphere, but there will be about 13 tons of oxygen in the air. The vessel is not designed to contain the pressure which would develop if all this oxygen were to combine instantaneously with sodium. Sodium burns slowly in air. Its latent heat of vaporization is 1 kcal/gm, whilst its heat of combustion is only 2 kcal/gm, so that half of this must be fed back to vaporize a further supply of fuel for the fire. The high thermal conductivity tends to conduct heat away from the burning surface, which is quickly covered with an insulating layer of oxide. A sodium fire will therefore not be self-sustaining at a high rate of combustion. The heat necessary for vaporization must be derived from some other source, i.e., the radioactive decay of fission products in the reactor fuel.

Conditions may be envisaged in which it has ceased to be possible to extract heat from inside the sphere. The temperature of the reactor rises, the neutron reaction closes down, but the emission of heat from the decay of fission products continues. In the worst case, all this heat might go to evaporating sodium. The burning of the sodium vapour produces twice the amount of heat absorbed in vaporization. All this heat might be transferred to the air. This, in turn, would transfer heat, by natural convection, to the steel pressure vessel, which would be cooled by the outer air. On these assumptions the air would reach a maximum temperature of about 644° F, and a maximum pressure of 16 psi some 15 minutes after the fire started. Making some additional allowance for barometric variation, etc., the design figure for the maximum internal working pressure of the sphere has been taken as 18 psi.

The internal pressure is not, however, the only criterion to be considered in designing the sphere. After the reaction has gone to completion and all the oxygen in the sphere has been consumed, the temperature would eventually fall, leaving a partial vacuum inside. The removal of the oxygen would leave an external pressure of 3 psi. The pressure at which it would begin to buckle depends on the uniformity of the steel shell. The most pessimistic estimate is that, at 5 psi external pressure, a shallow dimple, some 18 ft in diameter, would appear at the top. This would not raise stresses in the steel by more than 1 tsi.

## Capital Investment and the Cost of Nuclear Power

The practical utilization of nuclear energy on a large scale for the production of power requires the expendi-

ture of considerable sums of money for capital investment. This is particularly true if all phases of the nuclear-energy industry—from the mining of uranium or thorium to chemical processing of irradiated fuels—are included. Because of the complex nature of the problem, the wide variety of power-reactor systems, and the fragmentary information and experience available to-date, it will take some years before the question of costs can be discussed in concrete and specific terms.

The best American estimates for actual nuclear power plants are in the range of $235 to $250 (£84 to £90) per electrical kW of net power. These estimates include two pressurized water reactors and a boiling-water reactor ranging from 100 to 180 MW. Another estimate on a comparable basis for an aqueous homogeneous reactor falls within the same cost range. An American company has even advertised that it will build such a reactor at $210 (£75) per kW. On the other hand, a 100-MW fast breeder reactor is estimated to cost $450 (£160) per kW. In Britain, experience in the construction of Calder Hall indicates that 150-MW gas-cooled graphite reactors can be built for £120 ($336) per kW, about twice the capital cost per kW of a conventional coal- or oil-burning power station. All the above costs do not include fuel inventories in the reactor and processing plants.

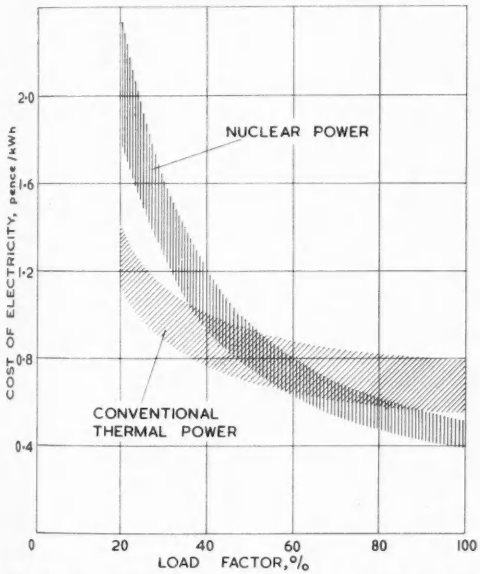



Fig. 28. **Comparison between nuclear power and conventional thermal power.**

The cost of producing electricity from nuclear energy depends on a large number of technical and economic factors, many of which are uncertain, so that estimates as to the overall cost per kWh of electricity produced are subject to a wide margin of error. It is generally accepted, however, that the cost of electrical power from a nuclear plant will decrease more sharply as plant size is increased than does the cost of electrical power from coal-fired plant. Thus, for instance, the cost of electricity from a 9000-kW boiling-water reactor has been estimated as about 21 mills* (1·6d) per kWh. Conventional plant of similar capacity will deliver electricity at about 12 mills (1d) per kWh. The 75,000-kW sodium graphite plant described in our September issue (p. 415) is expected to produce electricity at a cost of about 11 mills (0·94d) per kWh, as against 6 to 8 mills (0·5 to 0·7d) per kW from conventional plant of similar capacity. The 210,000-kW liquid-metal fuel reactor proposed by the Brookhaven National Laboratory (September issue, p. 420) has been estimated to produce power at 7·8 mills (0·67d) per kWh, thus making it competitive with conventional power stations. In Britain, estimates indicate that present designs of gas-cooled graphite-moderated reactors of 150 MW output would generate electrical power at a rate of 0·76d (9 mills) per kWh. This does not, however, take account of the value of plutonium produced. It seems reasonable to allow a credit for the sale of plutonium of somewhere between £5 to £10 ($14 to $28) per gram, thus lowering the net cost of electricity to at least the level of 0·6d (7 mills) per kWh, i.e., the cost of electricity from new conventional coal-fired power stations in the United Kingdom.

It must be pointed out, however, that, to be economical, the first nuclear power stations must be operated as base-load stations with an annual load factor of at least 60 to 80%. This is clearly shown in Fig. 28, which compares estimated costs from nuclear and conventional power stations, plotted against the annual load factor. These curves, of course, must be regarded as qualitative rather than quantitative.

Nuclear power will hardly be competitive with hydroelectric power, where such power is available on a large scale. Only when hydroelectric resources have been fully developed should they be used for operation at low power factors as peak-load stations, in conjunction with base-load nuclear stations.

## RESEARCH REACTORS

A research reactor may be defined as one which has been built for the purpose of gaining information, rather than for producing useful energy or transmuted substances. The information sought may be totally extraneous to the reactor itself or to reactor technology; the reactor then serves as a tool and a source of radiations (chiefly neutrons). Alternatively, it may be used as an object of research; a line is to be drawn here between research and advanced development in the pre-production stage; some pilot versions of industrial reactors, although, strictly speaking, of a mainly informative interest, are too closely connected with production programmes to be considered as research reactors.

Unlike the case of a power reactor there is no true economic basis on which to judge the merits of a research reactor, since it is almost impossible to make precise calculations of the value to be attached to its facilities. In fact, the nature of these facilities must depend to a very considerable extent on the location of the reactor and on the requirements of the potential user. It is one of the features of nuclear power that a great deal of information is required which can be obtained only from an experimental research reactor. Most of the nuclear constants necessary to evaluate reactor calculations have been obtained with the help of neutron beams from a pile, and little can be done on radiation effects on materials without the large fast fluxes available in a fairly high-power research reactor. The chemistry of the all-important transuranium elements could be established only after reactor-produced specimens of these elements had been made available.

It has been clear for some time that one reactor is not suitable for all the above-mentioned tasks. The nuclear physicist requires undisputed access to high-flux thermal and epithermal neutron beams, if possible without disturbance due to other work going on; the reactor engineer will wish to have many experimental loops in the reactor, so as to enable him to collect design information in the shortest possible time. As a rule, his space requirements are very considerable, leading to special design problems. Metallurgists, however, depend on large facilities with enough space for temperature control of the samples, high fast-neutron flux, and large

* 1000 mills = $1.

irradiation doses. If more advanced reactor information on shielding is required, it is almost certain that a reactor has to be devoted to these problems. Though few reactors have been known to be built specially for biological work, it is well to consider the conditions which determine these particular features.

PRINCIPAL TYPES OF RESEARCH REACTORS

(1) *Lowest-Energy Reactors :—*

Assemblies of fuel, moderator, and reflecting material, in which no provision has been made for heat removal, can be run either without any shielding (power of the order of a few watts, neutron flux close to the $10^7$ range) or with some shielding which allows the operation at a few kilowatts. Such a " zero-power " reactor can constitute either the easiest introduction to reactor technology in general, or a first step towards the construction of some definite novel type. In the latter case, running at a very low power may be required, so that the components do not become radioactive and can be approached and studied.

The " first reactors " using graphite and natural uranium were " CP 1 " (1942) in Chicago and " Gleep " (1947) in Harwell (the latter with some rudimentary cooling), and with $D_2O$ and natural uranium " Zeep " in Canada (1945), and " Zoé " in France (1948). In the present state of information and supply, it is unlikely that more such reactors will be built. On the contrary, the use of first-step " critical assemblies " is likely to develop, some past examples being " Lopo " built in 1944 at Los Alamos as a prelude to the development of the water boiler type, more recent critical experiments with plutonium solutions, and " Dimple " —a $D_2O$ and U assembly built in Harwell.

A zero-power reactor requires appreciably less fuel and moderator than a full-scale reactor of a similar composition provided with cooling and experimental facilities.

(2) *Graphite and Natural-Uranium Reactors :—*

A mass of graphite (several hundred tons) serves as moderator and reflector; the mass is traversed by several hundred cylindrical channels through which fuel elements are introduced and the cooling gas (usually low-pressure air) is blown. Examples are the X-10 reactor at Oak Ridge, Tenn. (1943); " Bepo " at Harwell (1948); Brookhaven, near New York (1950); and research reactors at present being built in Belgium and Western Germany. The fuel is metallic U in cylindrical rods or cartridges, usually clad in Al; the total amount of fuel in older versions is roughly of the order of 50 tons, whereas modern versions, thanks to improved quality of ingredients, may contain only 20 or 30 tons. The power ranges between 3000 and 30,000 kW, and the flux is around $10^{12}$.

As enriched fuel and heavy water become available, it is unlikely that many more such reactors will be built in the future for research purposes alone, since they are far too costly in ingredients and cooling machinery. Graphite and natural uranium remain, however, of interest for power production, and pilot plants of this type may be provided with research facilities. It is also to be noted that most of the radioisotope production, for which high fluxes are not necessary, but for which great volumes available for irradiation are useful, takes place at present in reactors of this type.

(3) *Heavy-Water and Natural-Uranium Reactors :—*

This type of chain-reacting medium has been of considerable importance in the research-reactor field. Its first representative (" CP3," of Argonne) was built in 1944 specifically for research purposes; subsequent development took place chiefly outside the United States. Specimens in existence or in project use a great variety of systems of cooling, covering a wide range of powers and fluxes.

Reactors provided with cooling by unforced circulation, i.e., in which convection carries $D_2O$ in a closed circuit through an external heat exchanger, are " CP3 " (1944-1951); Kjeller, Norway (1951); Châtillon (1953), replacing the French uncooled reactor; and Stockholm (1954). The maximum neutron flux is $1$ or $2 \times 10^{12}$, maximum power being about 100 kW per ton of uranium. At this flux level the radiation-induced decomposition of $D_2O$ is significant enough to necessitate the circulation of the gaseous atmosphere of the reactor tank through a catalytic recombination unit.

The first reactor to be cooled by compressed gas, and also the first $D_2O$-moderated reactor in which the coolant is brought to a high temperature, was the Saclay pile, built in France in 1952. The only reactor cooled by ordinary water is the " NRX " (Chalk River, Canada, 1947). This unique reactor offered for many years the highest flux in the world ($7 \times 10^{13}$) and still is remarkable for its numerous, large, and convenient experimental facilities. It is, however, more costly than most modern reactors and its power is too high according to the safety standards valid for most places in which a research reactor is likely to be located. The great bulk of the reacting medium, although not likely to be reproduced in modern designs, is an advantage from the experimenter's point of view. In Canada, reactor research is carried out in a single centralized establishment; in such conditions, as long as enriched fuel is not readily available, the NRX design remains competitive.

Fig. 29 shows a model of the NRX reactor, displayed at the exhibition recently held in conjunction with the Conference on the Peaceful Uses of Atomic Energy at Geneva. It indicates schematically the fuel, moderator, and coolant arrangement and one of the 18 self-serve mechanisms for the production of radioactive isotopes. The water-cooled steel shields above the calandria (aluminium tank which contains heavy water) weigh 15 tons each, and the concrete shields above the tank weigh from 17 to 19 tons each. Around the tank is the graphite neutron reflector, which weighs 58 tons. Beyond this are cast-iron thermal shields with from 7 to 8 ft of concrete. Each of the 176 fuel rods consists of a 32-ft aluminium tube in which is a 10-ft rod of natural uranium. River water flows down inside the tubes and over the uranium rods to carry away the heat. A single cadmium rod controls the reactor. Eighteen boron shut-off rods (only one is shown on the model) are driven into the calandria under air pressure for quick shut-down of the reactor. A photograph of the actual reactor installation is given in Fig. 30.

A further development of the NRX type is nearing completion at Chalk River. Details of this reactor, known as NRU, have been released at the Conference, when a scale model of the reactor, Fig. 31, was on public display for the first time. To enable the reactor core to be seen, the main floor and the concrete shielding around the core have been removed. The gun-like projections are tubes which run through the shielding to give access to positions of high neutron flux. Five of the eight 17-ton heat exchangers, with piping leading up to the core, can be seen in position below the core. The NRU reactor, which is scheduled to go into operation in 1956, will have a power and a neutron flux five times those of the NRX reactor. It will have a high flux over a relatively large volume, making it particularly suitable as a facility for tests related to the development of power reactors.

Like NRX, the NRU reactor will use natural uranium for fuel, in 200 rods, and heavy water as a moderator. However, a major difference in the design will be the method of cooling. As ordinary water is a much stronger absorber of neutrons than heavy water, the former has been kept out of the core of the NRU reactor. The heavy water will serve not only as the moderator but also as the coolant, i.e., it will circulate

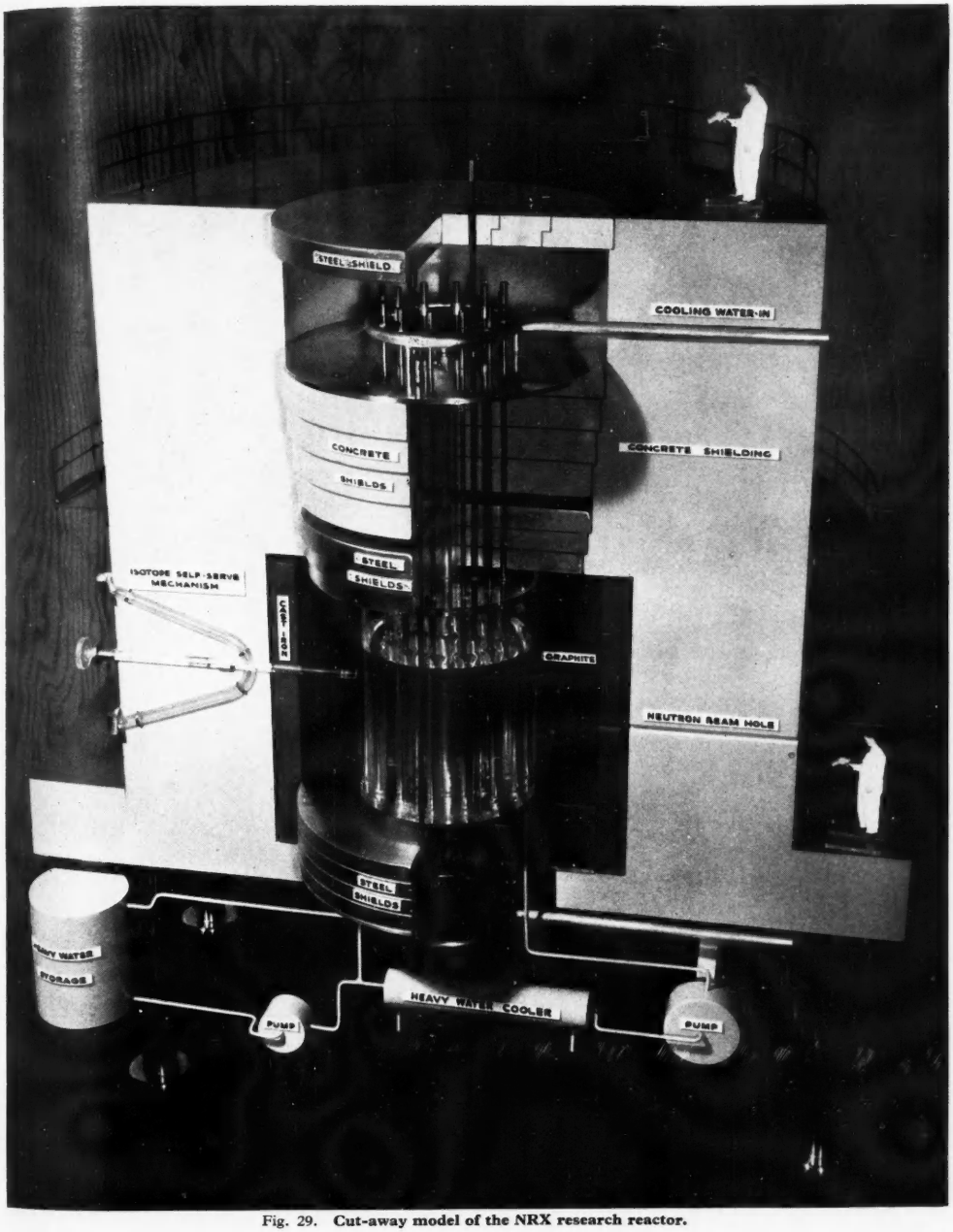



Fig. 29. **Cut-away model of the NRX research reactor.**

through the heat exchangers outside the reactor core. River water will flow through the heat exchangers to take the heat away from the heavy water, which circulates back into the reactor core.

About 200 fuel rods, sheathed in aluminium, will be inserted into the aluminium tank, which holds about 43 tons of heavy water. Some 16 cadmium tubes, sheathed in stainless steel, will act as both control and shut-off rods. Emergency dumping of the heavy water, in order to stop reaction, will also be possible.

In contrast with the NRX reactor, which has a graphite reflector around the tank, NRU has a water reflector, contained in an annular aluminium tank. Above and below the reactor tank, or core, are water-cooled steel shields. Around the tank is a water-cooled shield, 1 ft thick, and outside this are 9½ ft of concrete.

The main room in the huge building containing the reactor structure and experimental area is 90 ft high,

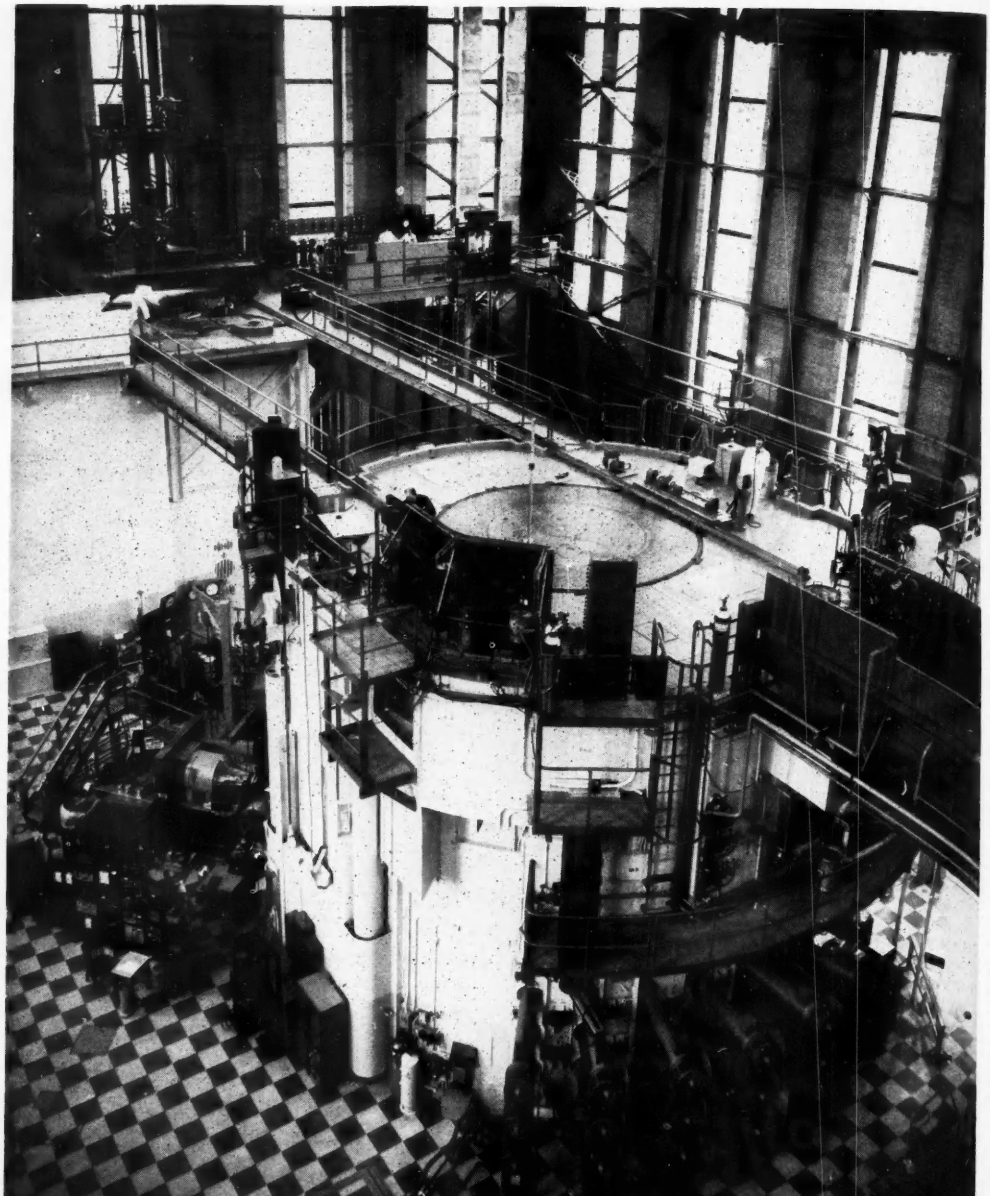


Fig. 30. **The NRX research-reactor installation.**

a large amount of space above the reactor being necessary to permit the removal of the fuel rods, which are raised up into a 225-ton shielded container, called a "rod-removal flask."

(4) *Heavy-Water and Slightly Enriched Uranium Reactors* :—

An interesting design recently completed in France ("EL3") is based on the use of a fuel containing about twice the natural amount of $U^{235}$. With this fuel, intermediate between natural and highly enriched, the characteristics of the proposed reactor fall between those of NRX and the highly enriched type (see section (7) below). There will be about half a ton of fuel in the form of metal cartridges. Maximum flux will be $10^{14}$ in the centre of an active volume of nearly 3 $m^3$. $D_2O$, under forced circulation, acts both as moderator and coolant.

Although the choice of these characteristics was dictated mainly by considerations of fuel supply, EL3, designed exclusively as a research reactor, may yet prove significant as a compromise between the modern trend towards low power and compactness, and the older, more spacious designs.

(5) *Water-Boiler Reactors :—*

In these reactors the highly enriched fuel is dissolved in ordinary water ; this liquid core is contained in a small stainless-steel vessel surrounded by the reflector and shield. Unless the reactor is run at a very low power, the core vessel must be provided with a gas circulation system in order to remove (and recombine outside the reactor) the hydrogen and oxygen produced by the radiation-induced decomposition of the water.

Several reactors of this type are in operation, amongst them being the Los Alamos Water Boiler " Supo." The fuel is in the form of uranyl sulphate. The moderator and solvent medium is ordinary water. Cooling is also by $H_2O$ flowing through a system of tubes immersed in the core, there being no contact with the fuel solution. Blocks of beryllia or, more often, of graphite serve as the reflector. In at least one project, the core vessel is to be surrounded by an outer tank containing $H_2O$ as reflector, the variation in water level then being used as the main controlling device. Experimental facilities include thermal columns, beam ports, and experimental channels of all types, as well as the all-the-way-through channel traversing the core. In view of the small core volume, the water boiler is best suited for beam experiments. Neutron flux is in the region of $3\times10^{12}$ at 100 kW.

In a project developed by North American Aviation Inc., the enriched fuel is in the form of uranium oxide mixed homogeneously with graphite powder ; cooling is by $D_2O$ circulating in a tubular coil. This design eliminates the recombination problem and some of the dispersion hazards ; it is, however, less compact, more costly than that of a " conventional " water boiler, and requires a somewhat higher power to produce the same flux.

(6) *Swimming-Pool Reactors :—*

In this type of reactor, a single mass of ordinary water (100 to 200 $m^3$) held in a concrete tank serves as moderator, main reflector, coolant, and first shield. The fuel assembly is attached to a steel framework which is suspended in the pool from a bridge spanning the pool width above the water level. The walls of the pool provide the residual shielding.

The fuel is 3 to 3½ kg (according to reflector quality) of highly enriched uranium combined with aluminium, the bulk of the assembled lattice being about 50 litres. No separate container is necessary for the moderating volume of water.

As mentioned above, the pool water fulfils the main reflecting function. The efficiency is improved if the lattice is surrounded by graphite or by beryllia (a 10-cm thick BeO reflector can be obtained by putting, around the periphery of the fuel assembly, an outer layer of boxes similar in shape to fuel elements, but containing BeO instead of the U-Al combination).

Temperature gradients resulting from the reaction taking place in the fuel plates produce a flow of water in the interstices between plates. Heat is thus drawn into the whole bulk of pool water, whence it is dissipated through the walls and by evaporation. This spontaneous heat removal is valid up to power levels of about 100 kW. To exceed this amount, the pool water must be circulated through an external heat exchanger connected with the pool volume through an inlet and outlet situated near the core. A factor of 10 in the power and neutron flux can thus be gained ; intermediate power levels are technically unprofitable. At a power level of 100 kW, neutron flux is up to $3\times10^{12}$.

In all swimming-pool reactors, the core is immersed

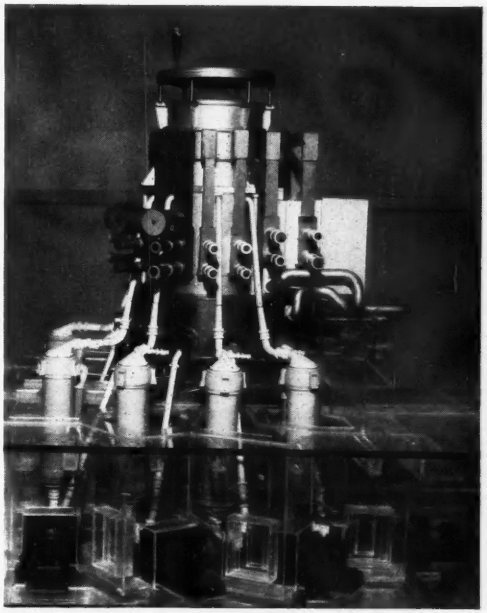


Fig. 31. **Model of the NRU research reactor.**

5 to 7 m in water, which affords the shielding in the upward direction. The side shielding presents variations from one project to another, according to the intended use of the reactor. The first swimming-pool reactor (Oak Ridge) was designed mainly to observe the interaction of radiation with bulky items of material, which could be simply immersed in water. In the simplest version, the core can be set in a fixed position, surrounded on all sides by several metres of water, and the tank can be embedded in the ground. In later versions the core was made movable between a central position (for bulk experiments, as above), and a corner position in which the core finds itself in the close proximity of a wall (the simple rectangular shape of the pool may in such a case be replaced by a more complicated shape, affording a convenient corner). The wall of the core-containing corner has then to be reinforced along familiar lines (concrete thickness of the order of 1·5 or 2 m). The usual beam holes and through-channels can then be provided, reaching through concrete and water to the immediate vicinity of the core. In a design proposed by the Bendix Research Laboratories, the proximity to the wall is generalized to the whole perimeter ; such a construction represents a transition from the " pool " principle to that of the " highest-flux " type (see Sec. 8).

Swimming-pool reactors actually built are that at Oak Ridge, in operation since 1951, and the special demonstration swimming-pool reactor at the Exhibition held in conjunction with the Conference at Geneva. Numerous swimming-pool reactors are, however, in the course of construction, most of these being scheduled to go into operation in 1956.

(7) *Heavy-Water and Highly Enriched Fuel Reactors :—*

In these reactors, specimens of which are the " CP5 " at Argonne, Illinois, in operation since 1954, and the "E443 " at Harwell, England, under construction, $D_2O$ is used as a moderator, coolant, and first reflector.

In the CP5, the fuel consists of a minimum charge of 1·2 kg of $U^{235}$ (about 90% pure), alloyed and assembled with Al, the core volume being about 200 litres. The moderator and first reflector comprise approximately 5½ tons of $D_2O$ in a single tank, forming

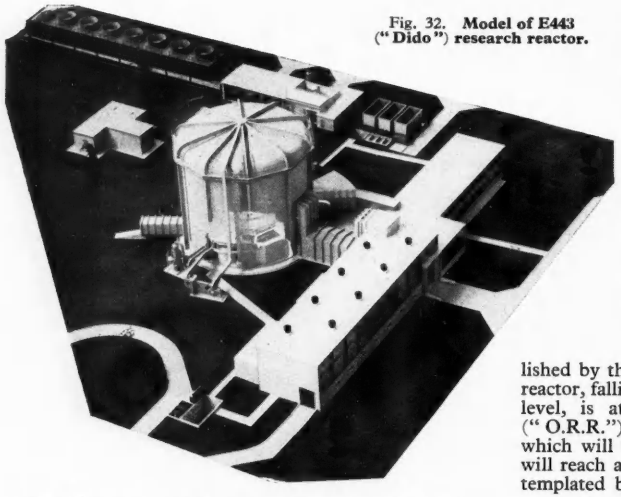


Fig. 32. **Model of E443 ("Dido") research reactor.**

a 60-cm layer around the core. The second reflector is a 60-cm layer of graphite around the tank. Cooling is effected by convection flow through the core and bulk circulation of $D_2O$ through an external exchanger. Shielding comprises about 150 cm of heavy concrete, lined on the inside with a few centimetres of lead.

The flux at 1000 kW is more than $10^{13}$ at the maximum point inside the core, falling gradually to $0{\cdot}5 \times 10^{13}$ at the tank edge. Cooling and other facilities are adequate for operation at 5000 kW, thus pushing the maximum flux towards $10^{14}$, but the 1000-kW ceiling is observed for safety reasons.

The CP5 type provides a high (but not the highest) flux, with insistence on a large number of experimental facilities and a relatively low power. The future of this type depends on the possibility of running at higher powers.

In the British E443 reactor ("Dido"), the reactor core consists of up to 2·5 kg of $U^{235}$ in the form of uranium-aluminium alloy plates arranged in boxes to form an approximate cylinder of length 60 cm and equivalent diameter 86 cm. This cylinder is in the centre of a cylindrical aluminium tank 2 m in diameter and 2 m in height. The elements are cooled by forced upward flow of $D_2O$, which overflows the top of the elements to become the reflector, before passing out to a heat exchanger for cooling and recirculating. Outside the aluminium tank is a graphite reflector of 60 cm thickness on the sides and bottom. The graphite is in turn contained in a steel tank which is helium-filled. Outside this tank is a biological shield of concrete, except for a section, 1·5 m square, occupied by a thermal column with appropriate shiedling at the outside. Below the reactor is a plant room containing pumps and a heat exchanger for the $D_2O$. The total heat removal catered for is 10,000 kW from the core, and 1000 kW from all experimental facilities, which consist of aluminium tubes entering graphite or $D_2O$ vertically or horizontally.

A model of "Dido," which will have the highest neutron flux ($10^{14}$) of any research reactor in Western Europe, is shown in Fig. 32. This reactor will be completed in 1956 and will be used for a variety of experimental purposes, including tests of fuel and coolant systems.

(8) *Highest-Flux Reactors :—*

Although a $D_2O$-moderated reactor affords the best possibility of producing a very high *slow* flux, designers aiming at highest possible fluxes should not forget the claims of the fast-neutron research; here, $H_2O$ asserts itself again. As regards cooling at highest powers per unit volume, both $D_2O$ and $H_2O$ are theoretically equivalent; in practice $D_2O$ demands additional guarantees against pollution and loss by leakage. Water is used both for moderation and for cooling, but (in the highest-powered type) neither as a reflector nor as a shield.

In the Materials Testing Reactor ("M.T.R.") at Arco, Idaho, operating since 1952, the highest-flux principles have been pushed to the farthest limit as yet reached. A preliminary reduced version ("L.I.T.R.") has functioned at Oak Ridge since 1950. More ambitious reduced projects have been recently published by the Oak Ridge staff, and a powerful research reactor, falling, however, somewhat short of the M.T.R. level, is at present in construction at Oak Ridge ("O.R.R."). A more powerful version of M.T.R., which will be run at a very much higher power, and will reach accordingly higher fluxes, is at present contemplated by the American AEC.

In the M.T.R. reactor, the fuel comprises 4 kg of highly enriched uranium, assembled with aluminium in standard fuel elements. As in swimming-pool reactors, the fuel, moderator, and first reflector are contained in the same tank. The size of the core is about 100 litres, though provision has been made for extending the volume up to 170 litres. Cooling is by means of $H_2O$ forced through the tank, the flow rate at 30,000 kW being 75 $m^3$/min. The first reflector consists of beryllia in blocks, pierced with channels for cooling; this reflector surrounds the core with a thickness of between 30 and 40 cm, while the second reflector consists of graphite, about 100 to 150 cm in thickness. The shield is made up of 10 cm of steel and 270 cm of heavy concrete.

The maximum flux of the M.T.R. reactor at 30,000 kW, situated in the reflector, is $4 \times 10^{14}$, with an available average of $2 \times 10^{14}$ and a fast (virgin) average of $1 \times 10^{14}$. In the O.R.R. reactor, the power may reach 10,000 kW or more, with an available flux of nearly $10^{14}$. According to the published figures, M.R.R. is some 5 or 6 times more expensive than the O.R.R. project; this may point to a law of diminishing returns, as applied to the efficiency of the present design at highest powers and fluxes.

### Other Research Reactors

The above descriptions by no means exhaust the numbers of research reactors in various stages of design, construction, or experimental operation. Thus, for instance, there are no less than three Russian research reactors which have actually been described in detail at the Conference. Of these, two are of a type using ordinary water and 10% enriched uranium, with a maximum neutron flux of $2 \times 10^{12}$ at 300 kW, and $2 \times 10^{13}$ at 2000 kW, respectively, while the third, in operation since 1949, is a heavy-water research reactor with a maximum neutron flux of $2 \times 10^{12}$ at 600 kW, though it is proposed to reconstruct this reactor to provide a maximum neutron flux of $2 \times 10^{13}$.

Furthermore, it should be remembered that there are to-day numerous novel reactor concepts, and that future types of research reactors will no doubt be developed from many of these beginnings. However, it has not been possible to give details of these types, in view of the fact that most of such details, by virtue of their very novelty, are still on the classified list.

(*To be concluded*)

# British Industrial Developments

## Drill for Gudgeon-Pin Holes

A machine for drilling the gudgeon-pin holes in pistons has recently been produced for Humber, Ltd., by Adcock & Shipley, Ltd., of Leicester. This machine, shown in Fig. 1, is of the horizontally opposed type, with two multi-spindle heads and a two-station fixture designed to enable two components to be drilled at one station whilst loading and unloading is carried out at the other.

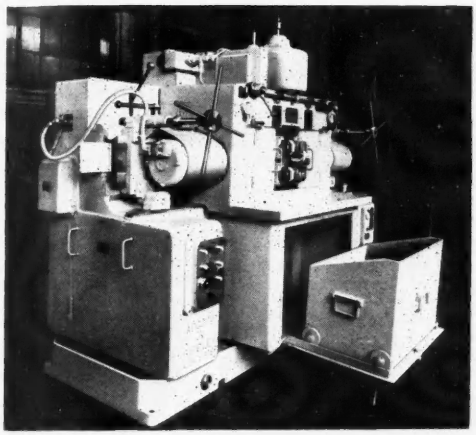


Fig. 1.

Special attention has been paid to the reduction of labour fatigue, while still retaining a high production rate, and also to the safeguarding of the operator. Manual operations have been reduced to a minimum by the use of hydraulic power for clamping and indexing the fixture. The indexing of the components in the fixture from the loading station to the drilling station and *vice versa* is performed by means of opening the two doors on either side of the fixture. The clamping of the components is controlled by two levers over the fixture, which also lock and unlock the two doors. The drill heads are automatically fed and stopped, working in a set cycle started by an electrical push-button. Thus, the actual running of the machine has been freed from unnecessary complications or handling in comparison with the work involved. Safety points incorporated are the necessity for two-handed operation of both the indexing and clamping mechanisms. A further safeguard is the two doors which cover both cutting tools and workpieces during the drilling cycles.

Fig. 2 shows the outer stations of the fixture, with the components in position and clamped. The pistons, when loaded onto the fixture block, are located on the bore and supported internally by a pair of "fingers" locating on the gudgeon-pin hole. The components are held, when clamped, by a vertical bar fitting securely over the crown of the two components. When unclamped, the bar moves clear of the component and pivots through 90 deg. into a horizontal position, giving adequate clearance for on and off loading.

The method of operation is as follows :—

(1) Two components at the front station are unloaded and loaded.
(2) The two levers at the left and right above the fixture are operated to clamp the components in the front station and to unlock the two doors.
(3) The doors are opened in sequence, first the right-hand and then the left-hand door, causing the fixture to index through 180 deg. and bringing the components to the drilling station.
(4) The doors are reclosed and the levers are operated, locking the doors and unlocking the clamp on the front station.
(5) The drilling cycle is started by means of the push-button.
(6) The components are unloaded and loaded, as in (1).

Once the initial cycle is completed, all further operations follow the same pattern, giving two completed components each time the fixture is indexed back to the front station. It will therefore be seen that the total production time for one piston is effectively only half the time of one drilling operation plus one indexing operation.

The machine is fed hydraulically by a servo-mechanism operated from cams rotated by a separate feed motor, the drive of which is equipped with pick-off gears to enable cycle times to be changed. The two-spindle drill heads are horizontally opposed and mounted on slides on the cabinet base. These heads are individually driven by 2-hp, 1430-rpm, rotor-stator units. Reamers of 0·854 in. diameter are fitted to standard collets, each having individual adjustments of 1 in. The drill heads themselves, by means of capstan-type wheels, have a hand adjustment of 6¼ in. Drilling is accomplished in a single stroke of the two-spindle heads. Speeds and feeds can be varied by means of pick-off gears. Provision is made for hand-feeding, indexing, and clamping for testing and setting-up purposes.

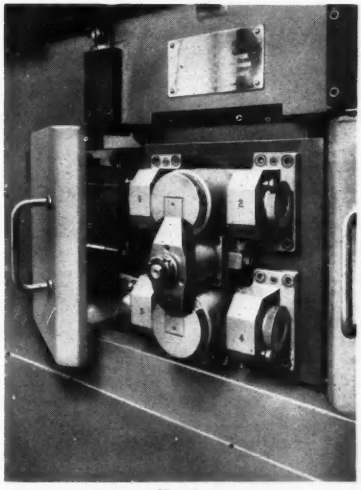


Fig. 2.

The machine consists of a base acting as a coolant reservoir, and upon this is mounted a box section containing the hydraulic control mechanism. On the extreme left and right of this are two cabinets extending forward. The left-hand cabinet fronted by its switch panel contains the electrical control gear, while the right-hand cabinet contains the hydraulic power unit and is fronted by its instrument panel. Lubrication is by a "one-shot" system to the drill-head slides and is operated by a foot pump near the floor level at the front

of the machine. Coolant is fed from a large-capacity centrifugal pump mounted in the base to guide bushes in the fixture, thus ensuring powerful jets to the cutting tools.

Special attention has been given to the problem of swarf accumulation, the front of the machine being equipped with a large sheet-metal cabinet, enabling coolant and swarf to be collected in a specially designed sheet-metal swarf barrow housed inside this cabinet. The barrow and the cabinet recess can be seen in Fig. 1. The bottom of the swarf barrow is fitted with grids to enable coolant to drain out, and the front of the cabinet is hinged at the bottom to allow the swarf barrow to be pulled out on its wheels, thus enabling it to be easily removed by a fork-lift truck and to be replaced by a similar barrow.

## Automatic Screw Feeding and Driving Machine

Operated pneumatically from a normal compressed-air supply of between 70 and 90 psi, the "Pneuma-Serve" automatic screw feeding and driving machine is now being manufactured in Great Britain by Guest Keen & Nettlefolds (Midlands) Ltd., of Birmingham. The machine (Fig. 1) consists of a hopper holding from 5 to 8 hours supply of screws, with an elevator and magazine, where they are selected individually and delivered to a cut-off plate and shuttle, from which compressed air chases the screws, *via* a tough plastic tube, to a portable driving head (Fig. 2), attached, if desired, to any standard power driver. As soon as one screw has been driven, the next screw is automatically fed and positioned, ready for driving.

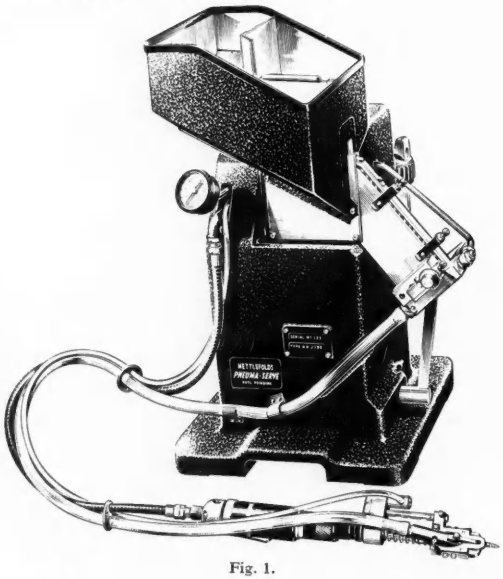


Fig. 1.

The standard power driver may operate from compressed air or electricity, and has a preloaded clutch which can be adjusted to the torque required to tighten the screw to the correct tension. If an air driver is used, an armoured plastic tube is coupled alongside the feed tube, or flexible cable if an electric driver is preferred. A third line connecting the head to the hopper is a small signal tube, synchronizing the operation of the hopper with that of the driving head, which has full mobility up to 20 ft and which can operate at any angle, including vertically upwards.

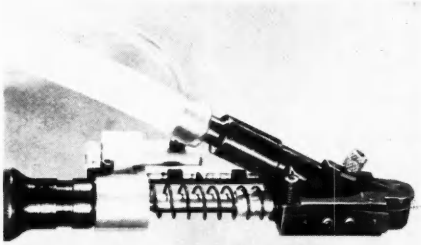


Fig. 2.

The machine can be produced to drive a large variety of screws up to 1¼ in. maximum length and from 0·1 to 0·25 in. diameter. Moreover, it will accommodate nearly all head styles, slotted or Phillips recess wood screws, self-tapping screws, and machine screws, including screws with washers attached. The hopper is light enough to be transportable, limited only by the length of the main air supply line. Provision is also being made for the production of special driver bits for both slotted and Phillips screws.

Among other advantages claimed for the "Pneuma-Serve" machine is the elimination of screw wastage and the handling of screws, thereby reducing material handled on assembly. Furthermore, screws can be driven four times more rapidly than by conventional methods, while the operator is not only protected from injury but is also subjected to far less fatigue.

## Refractory Product for High Temperatures

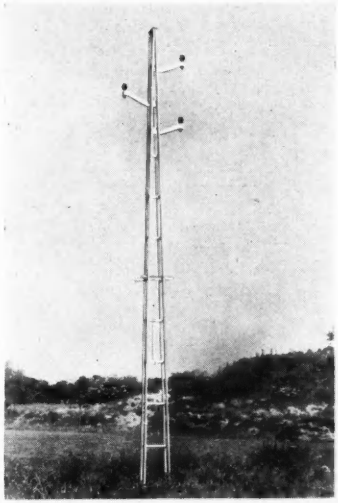
It is announced by The Lafarge Aluminous Cement Co. Ltd., of London, W.1, that "Secar 250," a white calcium aluminate hydraulic cement with an alumina content of 70 to 75% and with total impurities less than 1%, is now commercially available in Great Britain.

Refractory concretes or castable mixes incorporating "Secar 250" and a refractory aggregate have the normal setting time and ultra-rapid hardening properties usually associated with Ciment Fondu, but they also have a greatly enhanced refractoriness. For example, concretes made with "Secar 250" and corundum aggregate can be put into service at temperatures up to 1800°C, thus substantially increasing the range of refractory castable construction. It may also be used with other refractory aggregates, such as crushed firebrick, sillimanite, chrome, and chrome-magnesite. All such concretes can be put into service within 24 hours of casting, and it is stated that they do not shrink and that they have exceptionally high resistance to thermal shock.

## Overhead-Line Pole

A new overhead-line pole for use on distribution and transmission lines where supports do not have to withstand heavy mechanical loading has been developed by Painter Brothers Ltd., of Hereford, in collaboration with British Insulated Callender's Construction Co. Ltd.

In its design full consideration has been given to the need for economy, lightness, and simplicity of construction. These features have been achieved by fabricating the pole from standard commercial sizes of small-bore steel tubing and adopting a bracing system which permits a break-down of the complete pole into component pieces. This, in turn, results in easy transportation and enables assembly and erection of the poles to be carried out with the minimum of skilled workmen and supervision.



The new pole, designated the P.N. pole, is made in two sizes, i.e., 30 ft and 35 ft overall length, designed for a depth below ground level of 5 ft and 5 ft 6 in., respectively. The transverse face tapers from ground line to peak to form an " A " frame, with a reverse taper below ground to provide an efficient foundation. Longitudinally, the tubes are parallel. The pole is made from four steel tubes of 1-in. nominal bore. The tubes forming each longitudinal face are connected at intervals by batten plates welded to the tubes, and to these battens are bolted spacers, made from rolled-steel flats to form " I " sections, which connect the two longitudinal frames together to make the complete pole. The two longitudinal faces are fastened together at the top by a locking unit and a cap plate, which are connected by a through-bolt or insulator spindle. The cap plate also serves to seal the ends of the tubes from the atmosphere. All structural parts are hot-dip galvanized, bolts being hot-dip spun-galvanized. The tubes are left open during the galvanizing and are therefore protected both inside and outside.

The pole has been designed for an ultimate head load not exceeding 1250 lb at the pole top and has been subjected to full-scale comprehensive tests, so that poles are of a guaranteed known strength. Particularly suitable for tropical conditions, these poles will support a wide range of conductors on spans varying between 250 ft and 350 ft, depending on conductor size and material.

## Pilot-Operated Reducing Valve

An improved type of pilot-operated reducing valve, designated Class G3, has been introduced by Sir W. H. Bailey & Co. Ltd., of Patricroft, Manchester, to meet the growing demand for a valve which will not only deliver reduced pressure, irrespective of fluctuations in the inlet or boiler pressure, but which also will deal with variations in the demand or quantities of steam being used and which can be tightly closed when steam is not required.

The new reducing valves supersede the previous G2A series, improvements including a larger phosphor-bronze diaphragm, which can deliver steam at reduced pressures between 1 and 125 psi; a forged bronze or steel-alloy pilot-valve top; an austenitic stainless-steel pilot valve; and a nickel-alloy seating. Furthermore, to minimize the danger of distortion to the valve body through pipe strain, a new piston and piston chamber have been fitted. Maintenance is simplified, as the new valve is more easily assembled, while the spring chamber and pilot valve are more accessible for inspection. The separate pilot-valve strainer can be examined, if necessary, without dismantling the spring chamber top. A patented feature is a device which enables the valve to be changed over to remote control without breaking the cover joints.

## Descaling Compounds

It is believed that the problems encountered in weathering and other means of scale removal have been substantially overcome by means of the new descalers announced by Jenolite Limited, of London, W.1. These descalers are in jelly form and are applied to the steelwork after erection. In tests carried out over the last few years it has been found that these jellies, designated Jenolite DJ 1 and Jenolite DJ 2, will adhere to and react with mill scale on vertical steel surfaces for sufficient time to allow the most tenaciously adherent scale layers to be removed entirely. Thus, they eliminate the need for applying shop coats; furthermore, since the scale is retained to a great extent until after erection of the steelwork, the danger of severe rusting is very much reduced.

Jenolite DJ 1 is applied with flat brushes or swabs and is left for a period of about eight hours on the surface. No water rinsing or neutralizing is required and, after scraping and wiping off, the surface should be treated with Jenolite RRN in the usual way. Thus, complete scale removal, rust removal, phosphating, and paint bonding may be achieved in a few hours.

Jenolite DJ 2, an entirely different form, is designed for particularly heavy scale and should be left on the surface for approximately 24 hours. The steel requires washing down after descaling and, when dry, the treatment should also be completed with Jenolite RRN before painting.

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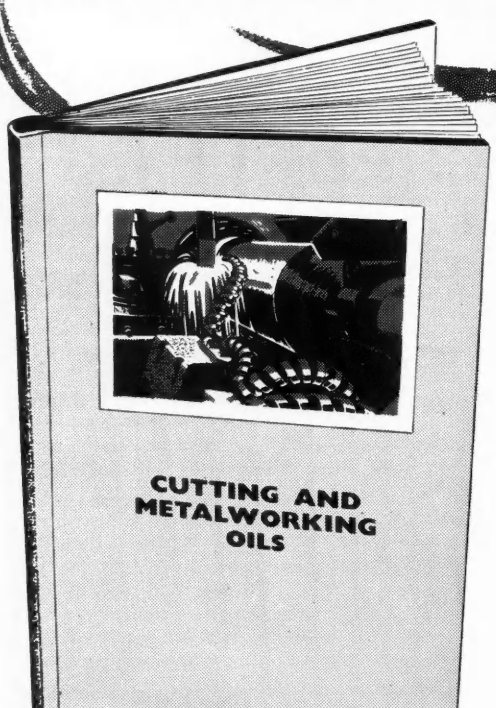


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# CLASSIFIED ABSTRACTS

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## CIRCUIT-BREAKERS

### Synthetic Methods for Interruption Tests on Circuit-Breakers.

By H. B. THORÉN. (From *Acta Polytechnica, Sweden*, Electrical Engineering Series, Vol. 6, No. 4, 1955, 60 pages, 26 illustrations.)

THE problem of testing circuit-breakers with higher breaking capacities than those which can be produced by existing testing stations has long given rise to considerable thought and discussion, and numerous synthetic methods have been proposed. The object of the present paper is to put forward a general theory of synthetic testing, to discuss the adaptability of the method to different types of circuit-breaker, to describe practical means of carrying out the tests, and to detail some results of comparative synthetic and direct tests.

In this paper, after propounding a general theory relating to synthetic test circuits, conditions for the equivalence between direct and synthetic tests are formulated. It is shown that it is theoretically impossible to obtain full equivalence between a synthetic and a direct test, if a test installation is used which produces a short-circuit power lower than the breaking capacity of the circuit-breaker to be tested. Some divergence from the conditions in a direct test must, therefore, be accepted, if synthetic testing is to be possible.

The influence of the arc voltage on the energy conditions of a circuit-breaker is calculated, and values of arc voltages for different types of circuit-breaker are given. From this, the possible increase in testing power by means of synthetic methods is estimated. It is shown that the multiplying factor of a synthetic circuit lies between two and six, the higher values being valid for very high voltages.

Different proposed synthetic circuits are discussed briefly. The circuit most in line with the general theory is the circuit utilizing a charged capacitor in connection with an oscillating circuit as the voltage-producing source. This circuit is shown to be able to reproduce the re-striking voltage correctly, even if a residual current is present in the test circuit-breaker. The practical realization of a synthetic circuit designed in accordance with this method is discussed, and the cost is shown to be relatively moderate.

Experimental research has been carried out with different types of synthetic circuit. The results of the tests are in close agreement with the theories put forward. The design of synchronized tripping circuits and other auxiliary equipment is described. The experiments confirm that it is possible to carry out synthetic tests with results which are in sufficiently close agreement with the results of comparative direct tests.

## ELECTRONICS

### A Dielectric Lens for Microwaves.

By K. S. KELLEHER and C. GOATLEY. (From *Electronics, U.S.A.*, Vol. 28, No. 8, August 1955, pp. 142-145, 16 illustrations.)

VARIABLE index of refraction, for the purpose of achieving focusing with microwave lenses, has become of practical interest to antenna designers within the past decade. This article discusses a form of variable index lens which is a microwave analogue of the optical magnifying glass. The lens is in the form of a disc, and its optical axis is coincident with its axis of symmetry. For focusing, the dielectric constant of the lens medium is varied in such a way that the index of refraction is a maximum at the centre of the lens and a minimum at the edge.

The major problem in constructing the lens is that of producing the required radial variation in dielectric constant. It would be possible, for example, for the lens to be fabricated from a series of concentric cylinders, with each cylinder composed of a different dielectric material. This, however, requires a large variety of dielectric material. A more adaptable approach is the placing of spherical voids in a base material of high dielectric constant. The size and spacing of the voids determine the effective dielectric constant, which diminishes with increased void size and decreased void spacing. This permits the use of Plexiglas, Teflon, and similar rigid base materials. This method was carried a step further by utilizing cylindrical voids instead of spherical voids, in order to eliminate machining complexities.

An experimental model of the lens was fabricated by laminating discs cut from 0·25-in. sheet Plexiglas. Cylindrical voids, ranging in diameter from 0·25 to 0·375 in. were drilled through these discs to form the lens medium. It was found practical to produce a fractional volume as high as 0·61 with Plexiglas as the base material. This gives a range of 1·53 to 2·6 in the value of dielectric constant, corresponding to a range of 1·24 to 1·61 in the index of refraction. The lens is 10 in. in diameter, 2·75 in. in thickness, and is designed to have a focal length of 10 in.

A series of more than 200 automatically recorded patterns was compiled in a detailed study of the lens. These patterns, measured at several frequencies, are the result of a performance study in which the illuminating horn was located on and off the lens axis and at various distances from the lens centre. The horns used at each frequency were designed to provide illumination tapered to −10 db between the centre and edge of the lens when the horn apertures are placed at the focal point and the beam directed along the lens axis.

Satisfactory performance over a broad frequency band is obtained when the lens is illuminated by a source on the axis. Moving the feed horn off axis has the general effects of shifting the main lobe by a corresponding amount and increasing the side lobe levels. Some improvements in off-axis performance may be obtained by moving the feed horn closer to the lens. With the feed horn 25 deg. off axis, patterns were measured at 8000 megacycles while moving the horn in 1 in. increments between 4 and 14 in. from the lens centre. These data show that best performance is obtained at 8 in. and indicate that the focal surface curves from the focal point towards the edge of the lens.

## FLUID DYNAMICS

### The Design and Calibration of a Variable Mach-Number Nozzle.

By J. ROSEN. (From *Journal of the Aeronautical Sciences, U.S.A.*, Vol. 22, No. 7, July 1955, pp. 484-490, 11 illustrations.)

THE ever-increasing demand for a more advanced wind-tunnel technique explains the keen interest recently shown in the development of devices for continuous variation of the Mach number. Some of these tunnels fitted with such devices can be characterized by their working principles, as, for instance, the sliding-

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block type, the flexible-wall nozzles, and the Drougge wedge.

The investigation described in this paper concerns a small flexible-wall tunnel (150×150 mm at the test section). To avoid the complicated mechanism generally characteristic of these constructions, a new method was found for affecting the flexible walls in a well-defined motion by means of one single-screw mechanism. The purpose of this tunnel is to study the Mach-number effect in some processes which previously were very difficult, or even impossible, to study in a set-up of conventional fixed-wall nozzles. As a comparison, some prominent features of the variable-nozzle design are as follows :—

(1) All measurements can be recorded continuously as a function of the Mach number.
(2) Time-wasting nozzle changes are eliminated.
(3) Starting of the tunnel can be performed smoothly.
(4) Instructive films can be taken of complicated processes, visualizing the influence of Mach number.

In the design of the nozzle, a Mach-number range from 1·5 to 3·0 was selected as being the most interesting for future needs. A flexible symmetrical nozzle was chosen, the following conditions being imposed for the contour :—

(1) At Mach number 2·5 the nozzle profile approximately corresponds to a Foelsch profile.
(2) In the whole Mach-number range only small curvatures are allowed.
(3) To obtain a rigid system the spring has to be short and strong.
(4) In order to avoid the pressure-changing sign along the flexible part of the wall, communication is established between the test section and the space outside the springs.
(5) The springs are rigidly clamped at the level of the test section.
(6) The inlet and throat contours up to the inflection point at the supersonic side are made from one sold block.
(7) Corrections for the boundary-layer increment have been estimated at 0·60 deg.

The results obtained show that the variation in Mach number is ±0·015 or less. The range of Mach numbers from 1·5 to 2·5 was obtained by one single-screw mechanism. The length of the nozzle from the minimum section to the beginning of the experimental test section was approximately constant and measured 4·5 test-section heights.

## GAS TURBINES

### Heat-Transfer Problems of Liquid-Cooled Gas-Turbine Blades.

By H. COHEN and F. J. BAYLEY. (From an advance copy of a paper submitted to *The Institution of Mechanical Engineers, London*, September 1955, 14 pages, 14 illustrations.)

IT is well known that one of the most important fields of development for the gas turbine lies in its operation at turbine-inlet temperatures much higher than those at present possible. Although high temperatures, of the order of 4000° F, corresponding to the combustion of fuel under stoichiometric conditions, are theoretically possible, such temperatures cannot now be used because of the inability of the metal components to operate at these levels. This difficulty is overcome for the present, at a high cost in fuel consumption, by pumping considerably more air than is actually required for combustion and using this excess to dilute the combustion products ; the gases are thus delivered for expansion in the turbine at a temperature sufficiently low to allow an adequate life for the various components which encounter them. To mitigate the reduction of efficiency due to this cause, much effort has been and is being expended on the use of means of improvement based mainly on heat addition, removal, or exchange at various steps in the cycle. This procedure inevitably results in a degree of complexity which seriously detracts from the most valuable feature of the gas turbine, i.e., its inherent simplicity. If, however, materials or techniques could be devised to operate at the order of twice the currently used turbine-inlet temperature, which would still be well below the maximum possible, much of this undesirable complication would be superfluous.

In this paper, a survey has been made of possible methods of cooling turbine rotor blades, and it is suggested that the most attractive is the thermo-syphon system, in which a quantity of liquid coolant is enclosed within each blade to act as a conveyor of heat to the more easily cooled root. The effectiveness of the system was demonstrated in experiments using a rotating apparatus, from which, also, the interesting result was obtained that, over a wide range, the heat transferred from the heated to the cooled ends of the thermo-syphon is independent of the quantity of coolant enclosed.

This result, which has great significance for turbine-cooling applications, has been confirmed in experiments with a static rig, from which further details of the mechanism of the heat-transfer process have been obtained. For the system using very small quantities of coolant, an ideal theory of the heat-transfer process has been postulated and this is in qualitative agreement with the experimental observations and suggests that internal blade-to-liquid heat-transfer coefficients will be so large compared with any others in a cooling system as to be effectively infinite—an assumption which is confirmed by comparison with results obtained from the rotating rig.

The heat-transfer process in the thermo-syphon, when the heated length is full of liquid, has been shown to depend largely on the motion of vapour bubbles within the liquid column and, on this basis, results obtained over a wide range of conditions have been correlated by dimensional analysis. In applying this system to the cooling of turbine blades it is most important to determine at what heat flow film-boiling will occur, since, at this condition, effective cooling fails. A criterion for the maximum rate of heat flow has been determined from the static-rig tests, but, like much of the data reported in the paper, it is in urgent need of confirmation by results obtained from tests on turbines or other apparatus operating under realistic conditions of speed and gas temperature.

## IRON AND STEEL

### Pearlite and Bainite Structures in a Eutectoid Carbon Steel.

By H. MODIN and S. MODIN. (From *Jernkontorets Annaler, Sweden*, Vol. 139, No. 8, 1955, pp. 481-515, 61 illustrations.)

WITH the aid of the electron microscope and the light microscope the pearlite and bainite formation was investigated in a eutectoid carbon steel after isothermal transformation. The electron-microscopic investigation comprised the preparation of plastic replicas and the direct reproduction of isolated carbide particles.

In agreement with earlier investigations the authors have found that the formation of pearlite mainly starts at the austenite grain boundaries and that a slag inclusion is often situated in the centre of the pearlite nodule. In confirmation of Mehl and others the authors have found that the transformation rate increases to a maximum between 600° and 550° C and that the rate of nucleus formation increases faster than that of the rate of growth of the nodules. With decreasing temperature the size of the nodules therefore decreases and thier number increases. This decrease is particularly pronounced between 700° and 650° C.

The smallest pearlite units observed always consisted of several ferrite and cementite plates. It has not been found possible to decide whether ferrite or cementite

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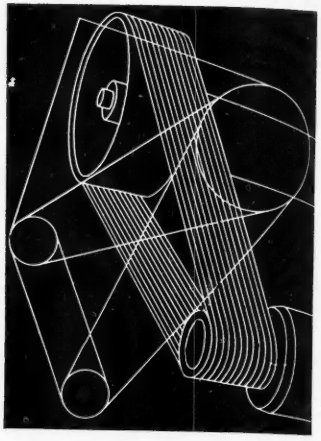

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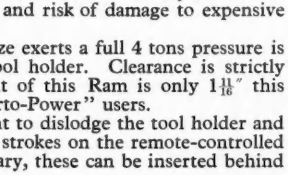

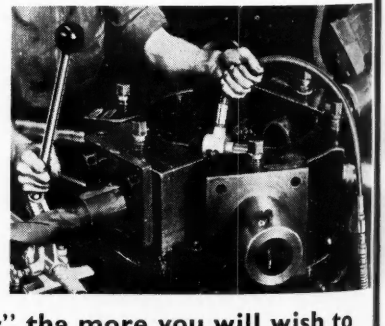

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starts the pearlite formation. The pearlite-austenite boundary is mainly smooth, i.e., ferrite and cementite appear to grow at about the same velocity, and neither phase can be said to be leading. A pearlite nodule consists as a rule of several fields with different direction of lamellae. The direction of lamellae in these fields is generally independent of the direction of radial growth of the pearlite, i.e., it generally seems to form a random angle with this direction. With the electron microscope it can be clearly seen that the nodules have a considerably more split and complicated appearance than a light-optical investigation indicates. The pearlite cementite has a jagged or comb-like appearance, and with decreasing transformation temperature the cementite plates decrease in size and thickness.

Bainite may be formed at the austenite grain boundaries as well as in the austenite grains. At higher transformation temperature the precipitation mainly occurs at the austenite grain boundaries. With decreasing transformation temperature the tendency for bainite formation inside the grains increases. Below 350° C the bainite formation in the austenite grains is fairly independent of the grain boundaries. For bainite formed above 350° C the bainite units formed at the grain boundaries are often feathery, but those formed inside the grains generally have the shape of rods, pointed at both ends, or of needles with long points. The bainite formed below 350° C has the shape of pointed lancets. From a maximum in transformation speed between 550° and 500° C the transformation rate decreases with decreasing temperature, the rate of nucleus formation decreasing more slowly than the rate of growth.

It is also shown that each separate bainite formation starts by a precipitation of ferrite. Carbide is then probably precipitated within the austenite enriched in carbon. Ferrite is the leading phase in bainite growth. With decreasing temperature the bainite structure becomes finer. Especially striking is the difference between the bainites formed at 400° and 350° C. The volume of the separate bainite units decreases on the whole with decreasing transformation temperatures from 450° C. Above 350° C the bainite formation appears to start with the precipitation of a group of parallel ferrite plates in the austenite. Between these primary ferrite plates thin tongues of ferrite seem to grow and gradually to form bridges between the plates. In the austenite enriched in carbon the carbide is probably precipitated. New plates of ferrite are formed parallel with the original plates and simultaneously with the growth of the original ferrite plates in their own plane. The austenite between the plates is enriched in carbon and successively transformed into an aggregate of ferrite and cementite. The bainite units formed in this way have a uniform parallel structure. The mechanism of bainite formation at 350° C and lower was more difficult to determine. It seems, however, as though each lancet were built up of several parts. Each such part consists of several relatively small ferrite and carbide units with a certain parallel structstructure. In adjacent fields the parallel structures form an angle with each other. The investigation has shown that the bainite carbides have the shape of a set of branches which mainly grows in two dimensions but which also branches out somewhat into space.

## METALLURGY

### Tensile Properties of Annealed Tantalum at Low Temperatures.

By J. E. BECHTOLD. (From *Acta Metallurgica, U.S.A.*, Vol. 3, No. 3, May 1955, pp. 249-254, 5 illustrations.)

THE mechanical properties of metals with a body-centered-cubic crystal structure undergo marked changes at low temperatures. These changes are usually characterized by a large increase in the yield strength and a sharp transition from a ductile to a brittle type of fracture. When tested in uniaxial tension at slow strain rates, these changes usually occur near −150° C in iron, near room temperature in molybdenum, and at about 250° C in tungsten. Similar marked changes in mechanical properties have not been observed in metals with the face-centered-cubic crystal structure.

The effects of temperature on the mechanical properties of tantalum, which is body-centered-cubic, have not been examined in detail. Tests by Druyvesteyn indicate that work-hardened tantalum retains some ductility as low as —180° C. The purpose of the present investigation was to determine the flow and fracture characteristics of tantalum, to establish if temperature affects its mechanical properties in the same way as it does other body-centered-cubic metals, and to disclose any major differences that might exist.

From the results of the investigations described in this paper, it is concluded that the yield strength of tantalum, like that of other body-centered-cubic metals, increases rapidly with decreased test temperature. The increase in yield strength is believed to be due to the ordering of interstitial solute atoms into preferred interstitial sites around dislocations. Tantalum, like iron, molybdenum, and tungsten, exhibits a pronounced upper and lower yield point. Some evidence of strain ageing was also observed around 200 to 400° C.

Unlike iron, molybdenum, and tungsten, tantalum did not exhibit a transition from ductile-to-brittle fracture at temperatures as low as—195° C. The reason for this is a very high stress for brittle fracture. A possible explanation of this high brittle-fracture strength is the relatively high solubility of oxygen in tantalum which prevents the segregation of oxides at grain boundaries. However, an alternative explanation could be a high critical stress for mechanical twinning. Mechanical twins were not observed in tantalum, although they have been observed in iron, molybdenum, and tungsten at low temperatures.

## ROLLING MILLS

### Friction of Steel Slabs on a Roller Table under Varying Physical Conditions.

By S. K. DEAN and M. A. KILBURN. (From an advance copy of a paper submitted to *The Institution of Mechanical Engineers, London*, September 1955, 10 pages, 9 illustrations.)

IN steel rolling mills, powered roller tables are used extensively to convey hot and cold products which are being rolled. The action of roller tables depends on the friction force between the surfaces of the rollers and the steel; consequently, a knowledge of the friction force is important for their design and operation.

When a steel slab lies on a horizontal roller table and the roller surfaces are slipping under it, there is a friction force acting on the slab which will accelerate or decelerate it. For the direct measurement of acceleration an accelerometer must be carried by the slab. This is difficult in steelworks, and therefore most of the measurements described in this paper were made on a model roller table in the laboratory, the results being compared as far as possible with some observations made in the works. In the model roller table used, the diameter of the rollers is 2 in. and the pitch 4½ in. These dimensions are about one-seventh those of a roller table of a primary reversing mill. The rollers are driven through a line shaft and bevel gears by an electric motor with accurate constant-speed control. The effectiveness of the speed control was checked by driving a tacho-generator from one roller and recording its output on a cathode-ray oscillograph while varying loads were applied. Mild-steel slabs $22\frac{1}{2} \times 5 \times \frac{1}{4}$ in. (the dimensions are about one-seventh those of a full-size slab) were used.

It was found that, when cold, the effective coefficient

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of friction was greater with a light slab than with a heavy slab, and was greater with low roller speeds than with high roller speeds. The effective coefficient of friction was independent of slab temperature in the range between 700 and 1000° C, while with hot slabs it was affected less by slab weight and roller speed. When the slip between the rollers and the slab became small, the effective coefficient of friction decreased with cold slabs and increased with hot slabs. The mean value with cold slabs was 0·20 and with hot slabs 0·29. Grit-blasting the slab surface increased the value by about 5%, while with heavily oxidized slabs the value was about 10% greater. Adding powdered mill-scale and water to the rollers increased the value with hot slabs by about 20% but not with cold slabs. Some observations in a steelworks support the results.

## SOLAR HEAT

### Performance of a Flat-Plate Solar-Heat Collector.

By G. T. WARD. (From an advance copy of a paper submitted to *The Institution of Mechanical Engineers, London*, September 1955, 16 pages, 15 illustrations.)

FOR many years, attempts have been made to produce heat and power from solar energy, with varying degrees of success. Two limitations, however, are placed on its economic utilization, i.e., the high capital cost of an apparatus for generating power from solar energy by the orthodox method of heating a working substance to drive a heat engine and the fact that, although solar heat may be economically obtained in a useful form in the tropics, the main demand for heat is in the temperate regions. It therefore appears that research should be concentrated both on the use of solar power by means other than the heat engine (for example, by the direct generation of electricity, using the thermo-electric effect, the photovoltaic cell, or the photo-galvanic effect) and on the utilization of solar heat in or near the tropics for such purposes as domestic heating, supply of hot water to laundries, cooking, distillation of water, drying, acceleration of chemical reactions, refrigeration, and air-conditioning.

Flat-plate solar-heat collectors have been used with some measure of success in Florida and California, and several firms manufacture units for this purpose. The literature is prolific in descriptions of particular installations in various parts of the world, and comprehensive bibliographies are available. Few attempts, however, have been made to correlate the quantity of useful heat obtainable at various temperatures with the variables involved.

The practical utilization of solar energy was considered in detail by a committee set up under the auspices of the N.P.L. in 1952. While concluding that at present there is no way in which solar energy can make a large contribution to the world's sources of power, the N.P.L. committee consider that domestic hot-water heating can be obtained in favourable circumstances and that there is scope in certain tropical areas for the distillation of water by use of a combination of solar heater and thermal pump. They also recommend that consideration be given to the development of air-conditioning equipment operated by solar heat and to the design of a flat-plate collector for driving a small engine. The present work was intended to be the first of a series of projects to implement the recommendations of the N.P.L. committee in the tropics, with particular reference to Singapore and the Federation of Malaya.

This paper describes the construction of an orthodox flat-plate solar-heat collector which is capable of being manufactured cheaply on a large scale. A simple relation has been established between the efficiency of the collector, the plate temperature, and the rate of insolation for constant rates of flow of circulating water.

A series of empirical design equations has been developed and charts have been constructed enabling the performance of the collector to be predicted with considerable accuracy. The method has been tested and found to be satisfactory in practice. It has been used to calculate the heat output or, alternatively, the ideal power output obtainable from the roof of a Singapore bungalow. The cost of supplying an average family with hot water from solar energy has been estimated and compared with alternative methods of heat supply. The work is being continued; a thermo-syphon type of domestic water heater has been completed and a forced-circulation type of flat-plate collector, 600 sq ft in area, is under construction. It is intended to use the latter to operate an absorption refrigeration unit for domestic air-conditioning.

## WELDING

### The Weldability of Titanium Alloy and Correlated Metallurgy.

By H. L. MEREDITH and C. W. HANDOVA. (From *The Welding Journal, U.S.A.*, Vol. 34, No. 7, July 1955, pp. 657-672, 20 illustrations.)

Two proprietary high-strength titanium alloys, one an all-alpha titanium alloy, and the other an alpha-beta titanium alloy, were developed for the purpose of finding a weldable material with properties equal to that of 8% manganese titanium alloy.

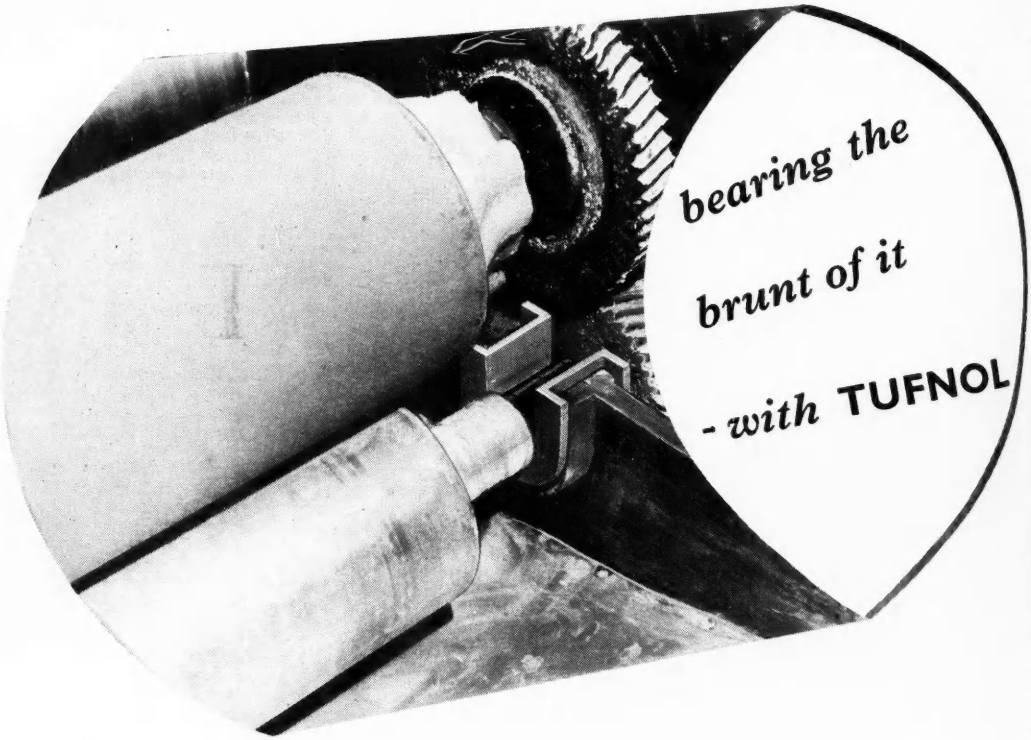
Both alloys have been found to be readily weldable by the inert-gas-shielded non-consumable tungsten-electrode process. The weldability of these two proprietary alloys was determined by several types of tests. The most important tests were weld bend tests, tensile tests, and circular patch-weld restraint tests.

Weld bend tests showed that the alpha alloy could adjust itself more readily to bending stresses (minimum bend radius of $5t$) in the as-welded condition than the alpha-beta alloy ($8t$). However, the latter's minimum bend radius could be improved to $4t$ by local torch transformation heating of the weld and heat-affected zone and consequently was considered highly satisfactory for its intended application. In either alloy, welds in square butt joints produced weld-joint tensile efficiencies exceeding 100%, both at room temperature and 700° F.

The circular patch-weld restraint test was used to reflect, in a qualitative manner, the ability of each alloy to withstand residual stresses set up by manual welding procedures and also potential strain-ageing effects on the alloy and weld so stressed.

The as-received welded alpha-beta alloy was found to be crack-sensitive with normal room-temperature ageing. The circular patch-weld restraint specimens developed transverse cracks through the welds approximately four months after welding. However, material which had been vacuum-annealed prior to welding did not develop transverse weld cracks after welding. Vacuum-annealing is a process used to stabilize the subject material and at the same time to remove interstitial hydrogen. Thus, by comparing the behaviour of the circular patch-weld restraint tests on the alpha-beta material, it became apparent that excessive interstitial hydrogen causes an unstable condition. This unstable condition progressively becomes worse with normal room-temperature ageing. Actually, it is suspected to be a gradual diffusion of the hydrogen in the alloy to areas of high stress, with subsequent reduction of the ductility of the material in these areas.

Vacuum-annealing (degassing) of alpha-beta titanium alloy sheet, which contains hydrogen in excess of 130 parts per million, has become common practice, in order to render the material more reliable for forming and welding applications. The as-received alpha alloy was not found to be as crack-sensitive as the alpha-beta alloy. Circular patch specimens have remained crack-free six months after welding.




Resistant to corrosion, overcoming all kinds of lubrication problems—TUFNOL certainly is the ideal material for engineering components. Take this TUFNOL bearing for instance. Supporting the inking roll on a wallpaper printing machine, it gives exceptionally long service—*lubricated by printing ink alone.* And being made of TUFNOL the bearing lasts many times longer than materials previously tried. Available in sheets or blanks, TUFNOL is easily and accurately machined with the usual engineering tools; or we will gladly produce bearings to your specification if you prefer. In either case, our Engineers are *always* at your disposal.

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REGISTERED TRADE MARK

An ELLISON Product

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# New Materials, Processes, and Equipment

## MACHINE FOR BALANCING COMPLETELY ASSEMBLED MOTOR-CAR ENGINES

Although, of course, separate balancing of the component parts of an engine is essential, there can be no doubt that a machine for balancing completely assembled motor-car engines is of great value. Such a machine is that manufactured by Hofmann Machine Tools, of Davyhulme, Manchester.

In this machine, the drill units, seen in the illustration, can be positioned according to requirements. Other interesting features include a quick-acting arrangement for mounting and locking the engine for drilling, and a quick-acting connection between the engine and the main drive spindle. The drive stand incorporates an additional locking device which ensures keeping the correct angular position and prevents the whole engine itself from rotating. The electrical measuring system used is such that balance is achieved without residual moments. In addition to the equipment for measuring the degree of unbalance in each plane, two " dummy " indicators are provided for each compensation plane, and these can be set by the operator in accordance with the detected and observed values. The necessary trip gears and filter links are permanently installed in the machine, so as to eliminate vibration.

## DISC PUMP

A new addition to the " Alcon " range of pumps produced by Arthur Lyon & Co. (Engineers) Ltd., of London, W.1, is their disc pump, intended for dealing with water containing abrasive material, solids in suspension, mud, liquid manure, etc. The new pump comprises a cast-iron pump chamber, on which is mounted a 1-hp Villiers or J.A.P. petrol or petrol/paraffin engine driving a worm gearbox, which in turn transmits the motion through a linkage mechanism to the pump spindle.

The pump has been designed to run continuously with the minimum of maintenance, and lubrication is limited to keeping the gearbox and engine sump topped up with oil. The bearings on the crank spindle are grease-packed and need no attention between major overhauls. The bearings at the middle of the top arm and in the pump are of special material which require no lubrication. All other bearings in the connecting linkage are of the rubber-bush type and also need no attention. The flywheel fitted to the engine ensures consistent running and, as the pump runs at a relatively low speed, economy in fuel consumption (estimated as 12 hours running on one gallon of petrol) and long life are assured. The diaphragm and non-return valve are made of a special grade of rubber interleaved with canvas, while the pump spindle and top bearing spindle are constructed of stainless steel. Two lip-type seals are fitted in the pump, to prevent leakage from the pump chamber. The top casting is so constructed that a pocket of air is trapped during pumping, absorbing shock and evening out the pumping rate.

The pump, which weighs 180 lb, has an output of 1200 gallons per hour, maximum head and suction lift each being 20 ft.

## KNEE-TYPE MILLING MACHINES

A completely new line of knee-type milling machines, with spindle drives of from 7½ to 10 hp and feed drive motors of from 1½ to 2 hp, has been developed by the Kempsmith Machine Company, of Milwaukee, Wisconsin. Designed to take full advantage of modern cutting tools and techniques, these machines incorporate many outstanding features, including rigidity, accuracy, flexibility, and ease of operation.

The spindle is powered by an individual spindle drive motor through a highly efficient gear train which provides 18 speed changes over a range of from 25 to 1500 rpm. An ingenious electrical spindle control eliminates all couplings, friction clutches, and similar devices. A separate feed drive motor, also operating through a gear train, provides 18 feed changes over a range of from ⅜ to 45 in. Both speed and feed changes are made through direct-reading dials.

Electrical push-buttons located on the front of the knee, as well as on the side of the column, start and stop the machine. The power-feed controls are grouped on the front of the knee within easy reach of the operator and are directional. Although hand-feed controls are provided, these are used only for making minor adjustments.

A specially designed rectangular overarm is dovetailed to the massive column. The face of the column is of extra width for rigid support of the extremely

# A remarkable NEW head telephone set by Standard

Here's the most interesting telephone news for years! A new, lightweight, one-piece head telephone set moulded in nylon plastic and weighing only 4 oz!

Available in black or ivory finish, this revolutionary instrument, designed, developed and manufactured by Standard Telephones and Cables Ltd., for telephone switchboard operators, introduces an entirely new concept in comfort, elegance, economy and operational efficiency.

No other operators' head telephone set available today has all these additional advantages:—

***Self-contained nylon moulding incorporating high quality, super-sensitive transmitter and receiver.***

***Weight only 4 oz! (compare this with the 15 oz weight of the conventional head and breast type operators' set).***

***Attractive appearance.***

***Only one instrument cord required.***

***Finely balanced to ensure comfort and stability.***

***Mechanical shock absorber to avoid breakage at transmitter horn junction.***

***Adjustable head grip with resilient band.***

***Moulded frame for operator's indentification label.***

*Ask for brochure TD.16 which fully describes the*

**Another advance by Standard**

# 4406 Telephone Head Set

## Standard Telephones and Cables Limited

Registered Office: Connaught House, Aldwych, London, W.C.2

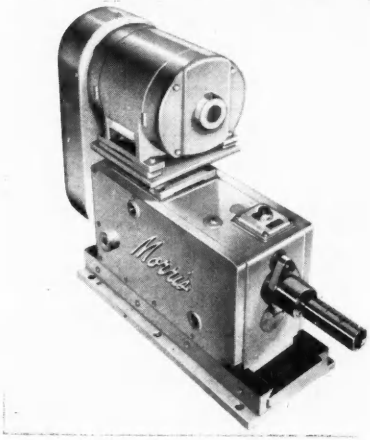
**TELEPHONE DIVISION**
**OAKLEIGH ROAD · NEW SOUTHGATE · LONDON, N.11**

broad knee, which in turn gives the maximum of support to the saddle. A narrow dovetailed guide supplies additional hold-down to the saddle to prevent arching and furnishes an effective path for smooth and precise travel of the saddle. The spacious table is engineered so that the saddle-ways are never uncovered at full travel. An oversize leadscrew eliminates elasticity in the drive. Large bronze leadscrew nuts are of the locking type and are directly adjustable from the front of the saddle. This simple and effective backlash control contributes to effective climb-milling.

## CAM-FED DRILL UNITS

A new range of cam-fed drill units, which incorporate adjustable thrust control and which can be used for drilling, tapping, and allied operations with automatically controlled operational cycles, is announced by the Morris Machine Tool Company, of Cincinnati, Ohio.

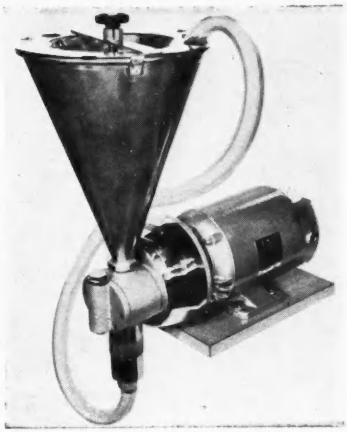
A feature of the new units is an electric clutch, in place of conventional linkages and power-transmission devices. A rheostat permits supplying varying amounts of current to the electric clutch for effective adjustable thrust control. The amount of thrust required for a particular job may be dialled directly on the rheostat. Should the drill unit encounter an obstruction, the electric clutch will slip, preventing damage to the unit and to the workpiece. By adjusting the rheostat for thrust just beyond the maximum required for the operation, it is possible to use the electric clutch as a dull-drill detector. When the drill becomes dull, or is broken, the clutch will slip, preventing off-size holes or poor drilling. A buzzer or warning light may be wired into the circuit to signal when the drill becomes dull.



The new units, which are automatically cycled, utilize a heavy machined cam to provide forward motion to the quill. The periphery of the cam determines the rate of rapid approach, the drilling time, the length of stroke, and the rate of rapid return. Mechanical devices, travelling with the quill, trip limit-switches to end the cycle or to reverse the quill travel and spindle rotation for tapping operations. Extra-rigid quill construction prevents spindle "hangdown," while a completely separate compartment is provided for changing pick-off gears.

## SELF-CONTAINED ULTRASONIC HOMOGENIZER

Known as the "Minisonic," the new self-contained homogenizer announced by Ultrasonics Ltd., of Otley, Yorks., uses the principle of emulsification and homogenization by ultrasonic cavitation, and makes possible the transfer of a product from the laboratory stage



straight into full-scale production, without altering the manufacturing technique.

The "Minisonic" is so constructed that it represents a completely self-contained unit. No pre-mix vessels or ancillary plant are required, and emulsions can be prepared to any given formula in batches up to one gallon. The continuous phase in the primary funnel can be re-circulated *via* the vibrating element, using a flexible hose, and the disperse phase can be introduced through the inner funnel at regulated speed. The finished product can be discharged, also by means of the flexible hose. Pre-mixed emulsions are processed by using the primary funnel without the inner funnel.

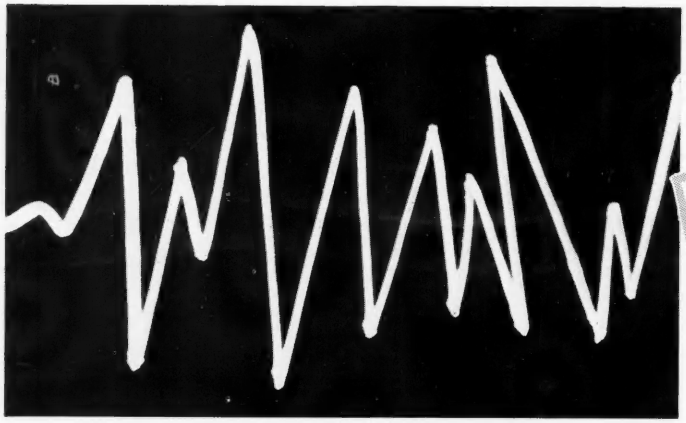
All parts in contact with the liquid are fabricated in 18/8 stainless steel or corrosion-resistant alloys, ensuring absolute cleanliness in operation. The vibrating element can be dismantled quickly, and adjustment is very simple. The removable resonant bell is supplied complete with tail-piece and a length of thick-walled P.V.C. hose. The high-speed precision gear pump is designed to combine efficiency with long life. The prime mover is a ½ hp squirrel-cage, screen-protected motor, directly coupled to the pump.

## HEAVY-DUTY, OPTIONAL-SPEED SANDER-GRINDERS

The new 7-in. heavy-duty, optional-speed sander-grinder announced by Black & Decker Limited, of Harmondsworth, Middlesex, delivers 90% more power, yet is lighter in weight than the 7-in. heavy-duty sander it replaces. It is available in three models, with spindle speeds of 4200, 5200, and 6000 rpm respectively, each unit being designed for a specific range of work. Thus, the low-speed and standard models are suitable for use with planer heads for wood, saucer grinding wheels, wire cup brushes, and sanding discs, while the high-speed machine has been designed primarily for use with nylon-bonded, depressed-centre cutting-off wheels, which require high speeds and constant power for satisfactory operation and which are extremely versatile, inasmuch as it is possible to rough-grind, finish-grind, and notch a wide range of materials, from cast iron to marble, with the same wheel.

Features of all three models of the new sander-grinder include grease-sealed ball bearings requiring no periodic lubrication; heat-treated spiral bevel gears; protection of the front of the main housing from wear and breakage; easy inspection of commutator and brushes; deflection of exhaust air away from the operator; protection of the switch from abrasive dust and from being accidentally knocked "on"; and a comfortable rear handle with plenty of finger room.

Some of the applications for this new tool, when



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MACHINE FIXING GLUE
**COOPERS**
**FELT**

## INDUSTRY IS Shocking

If you could calculate the loss of efficiency caused by vibration you wouldn't wait to write to Coopers, you would wire. When you realise that the Croid-Cooper method of machine installation also enables you to change layouts overnight—well, where's that telegraph form ? We should a'so welcome your enquiry by telephone or letter.

**COOPER & COMPANY (BIRMINGHAM) LIMITED**

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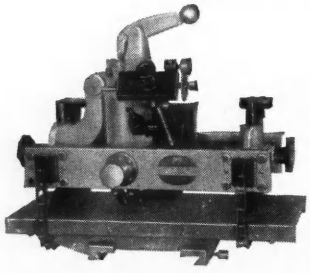
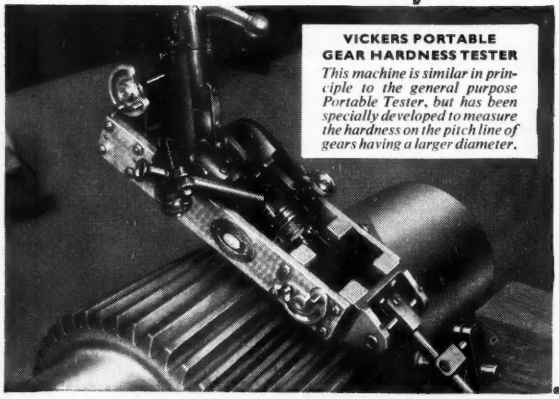


## HARDNESS-TESTING MACHINES
that combine
## Portability with Precision



**VICKERS PORTABLE GEAR HARDNESS TESTER**
*This machine is similar in principle to the general purpose Portable Tester, but has been specially developed to measure the hardness on the pitch line of gears having a larger diameter.*

The Vickers Portable Hardness-testers incorporate all the essential features of the famous Pyramid Hardness-testing machine and enable exceptionally large and heavy specimens to be tested with great precision. An indenter of the standard Vickers shape is used in conjunction with the Micrometer Ocular so that all readings obtained are the well-known VPN.

*Please send for a catalogue giving full details*

**Vickers - Armstrongs Ltd.**
*13 City Road · London · E.C.1.*
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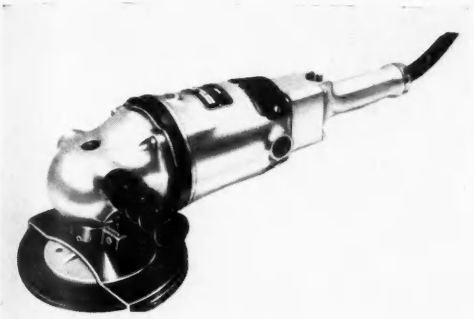


fitted with a depressed-centre disc, include cutting off gates and risers on ferrous and non-ferrous castings, grinding down welds on railway wagons and coaches, smoothing flame-cut edges on heavy steel plates, cleaning between the teeth of heavy industrial and marine gears, cleaning off rust and scale from girders and rails, scurfing and bevelling prior to welding, cutting sheet metal for motor-vehicle panels, refacing die and press blocks, removing rivet and bolt heads, cutting off angle iron, cutting insulating material to size, and cutting off magnesite and high-alumina refractory bricks.

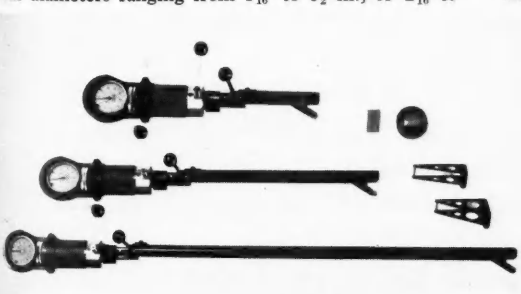
Owing to the construction of these discs they show great economy in use. In addition, they are extremely robust, and wheel breakages are negligible. To ensure perfect safety, however, two wheel guards are available for use with the sander-grinder. These guards are manufactured to suit 7- and 9-in. diameter depressed-centre wheels, and are designed to clamp onto the spindle bearing boss of the tool, being held in position by means of a clamp and fixing bolts. A 7-in. sander-grinder, fitted with a nylon-bonded, depressed-centre cutting-off wheel guard is shown in the illustration.

To provide the minimum of rotating weight with the maximum of flexibility for sanding with 7-in. abrasive discs, the new tool is supplied with a 5-in. diameter moulded-rubber backing pad and a $6\frac{3}{4}$-in. diameter plastic disc, known as a " Koolflex " backing pad. For 9-in. discs, an $8\frac{7}{8}$-in. " Koolflex " pad is available as an extra. Should a more rigid backing be required for the larger sanding discs, the two " Koolflex " pads can be used together.

## INTERNAL HARDNESS TESTER

Manufactured in Austria by Maier & Co., of Hallein, and distributed in Great Britain by Stanton Machine Tools Ltd., of West Molesey, Surrey, the " Emco-Intest " internal hardness tester is the result of many years of research and should fill a definite need in many branches of industry.

Designed for the testing of surfaces in long bores, with diameters ranging from $1\frac{3}{16}$ to $6\frac{1}{2}$ in., or $2\frac{7}{16}$ to $8\frac{7}{8}$ in., it enables the operator to test any point inside these bores to a maximum depth of 118 in. In this connection, the instrument can be supplied in three standard depth ranges, as illustrated, i.e., up to $4\frac{1}{2}$, 16, and 36 in. respectively. Special instruments suitable for maximum depths up to 118 in. can also be supplied, in accordance with requirements.



The instrument, the test-load transmission of which has been patented and ensures the highest accuracy without friction, can not only be applied to parallel and tapered bores but will give accurate direct readings on the Rockwell scale in any position.

## TONG-ACTION, LOW-VOLTAGE SOLDERING TOOL

Based on the principle of heating the job directly, instead of depending on first heating a mass of metal from which a small amount of heat is transferred, the " Venum " tong-action, low-voltage soldering tool announced by the sole concessionaires, Aircraft Services & Export Ltd., of London, S.W.1, employs a pair of tongs which act as leads for the electric current supplied to special electrodes. To solder, the parts are held in the tongs and a button is pressed ; the solder is run, the button is released, and the job is completed, producing a sure bond almost instantaneously, without heat loss, waste of time, tinning, oxidation, or cleaning.

The stems are detachable and interchangeable and, coupled with the use of special carbon electrodes, permit all types of work to be catered for ; in addition, many otherwise inaccessible positions can easily be reached, while the dismantling of parts to be soldered is reduced to a minimum, as the quick-action localized heat produced does not harm adjacent insulation. The tool can be operated from a 6-V battery or from the mains *via* a transformer, with very low current consumption, varying to some extent with the thickness of the material to be soldered. As no preheating is necessary, current is required for only the few seconds needed to do the actual job. The same tool can be used for soldering solid material from $\frac{1}{64}$ to $\frac{1}{2}$ in. in diameter, or equivalent surfaces, in copper, brass, or other solderable metals.

## MINIATURE HIGH-PRESSURE PUMP

Developed by Charles S. Madan & Co. Ltd., of Altrincham, and intended to fill a gap between their standard types of " Airhydropump " and hand pumps, the new Junior model " Airhydro-pump " is only 12 in. in length by $3\frac{1}{4}$ in. in diameter, weighs $16\frac{1}{4}$ lb, and provides, in a range of six models, hydraulic pressure from 100 to 10,000 psi. These pumps are operated by

*The illustration on the left is from an old photograph in the Tangye Museum, which was taken during the launching of The Great Iron Ship.*

*Since Brunel launched*

# THE GREAT EASTERN

SOME of the earliest Tangye Hydraulic jacks were used to launch this great ship. Hydraulic engineering was then in its infancy but since that time this great power has proved an increasing influence on the pattern of engineering design.

The convenience and simplicity of controlled hydraulic pressure, harnessing almost limitless power, lends itself to many applications ; Tangyes Limited are still engineering such uses for the benefit of British Engineering Prosperity.

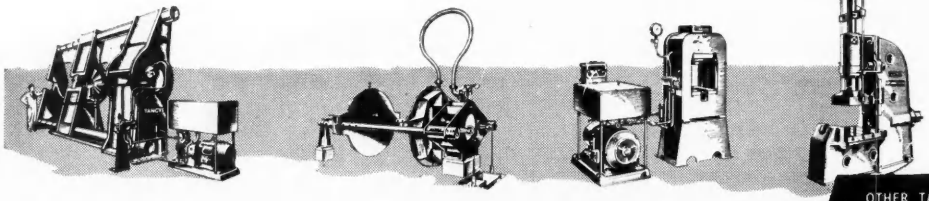
**When you are talking "HYDRAULICS" let "TANGYE" join in.**

*A 400 tons capacity Wheel Press for the high-tonnage assembly of railway wheels, etc. Ram is arranged for hydraulic return.*

*A Pipe Testing machine. Hydraulic pressure seals the ends of the pipe which is subjected to pressure test.*

*A 100 tons capacity Inverted Press specially designed for rapid production of watch cases.*

*A 50 tons capacity Open Gap Forging Press with vertical and horizontal rams 18" and 10" strokes respectively.*



TANGYE HYDRAULIC DIVISION

OTHER TANGYE DIVISIONS ARE
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• ENGINES DIVISION
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compressed air, minimum 20 psi, maximum 100 psi, and, as they are constructed of non-corrodible materials, they can be used with either water or oil. There are no metal-to-metal moving parts and maintenance costs are negligible.

An air-reducing and control valve enables any required hydraulic pressure in the range of the pump to be produced but not exceeded. Once the pump has been set to give the required pressure, no further adjustment is necessary, and on a closed circuit the pump will maintain the pressure exactly for an indefinite period without air consumption.

These pumps are especially suitable for the pressure-testing of valves and small fittings. As a unit used as a source of hydraulic power, they are also suitable for the operation of small presses, jacks, rams, and many other hydraulic mechanisms.

## IMPROVED DRAWING BOARD AND DESK

With any drawing board, visibility and accessibility are no problems up to 12 in. from the bottom of the drawing. Beyond this point, however, a draughtsman usually has to bend, stretch, or stand as he draws on the upper portion of his drawing. By means of an improved drawing board and desk, produced by The General Fireproofing Co., of Youngstown, Ohio, this problem has been solved by providing a means of bringing any desired part of a drawing to the draughtsman himself, thereby eliminating the need for stretching or standing.

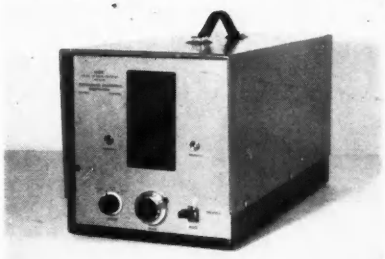
The basic idea is simple :—The drawing platform is equipped with a patented, endless vinyl-plastic belt. This belt, which is 48 in. in width and can accommodate a drawing 72 in. in length, is wrinkle-free, provides an ideal drawing surface, and features a self-healing characteristic which prevents pencil grooves and compass-point holes. The belt is moved by a patented positioning device consisting of two anodized aluminium rollers, one of which is located at the back and the other at the front of the drawing platform. By merely turning a wheel at either end of the front roller, the draughtsman can move the belt and the drawing affixed to it, so that any part of the drawing is brought well within his range of visibility and reach.

Fully adjustable in tilt from horizontal to 85 deg., the drawing platform, which is constructed of reinforced steel to prevent warpage, will accommodate any normal type of draughting machine, lamp, or parallel straight edge. Furthermore, the platform can also be adjusted for height between 31 and 39 in. Incorporated in the back of the steel desk on which the platform is mounted is a large storage area, into which bookshelves and letter- or storage-drawers are installed, to suit individual requirements. A sliding reference top—on which the draughtsman can make notes, refer to auxiliary drawings, etc.—can extend up to 18 in. from the rear of the desk.

It is claimed that the new device, designated " Draft-A-Matic ", not only eliminates the disadvantages of stretching and standing, but also provides ample storage space, within easy reach from the normal seated position, obviating the need for auxiliary tables, files, or bookshelves, and resulting in a substantial saving of floor space.

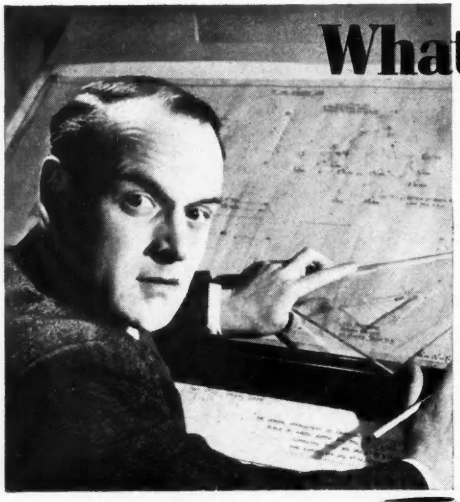
## DIGITAL VOLTMETER

The sensitivity of the new digital voltmeter announced by the Consolidated Engineering Corporation, of Pasadena, California, is such that 10 mV provides



full-scale digital output (999). Controls permit selection of any voltage in either of two ranges (10 to 25, and 20 to 50 mV) for full-scale read-out. Digital output appears on an illuminated panel for visual readings, and is also available through contact closures representing three decimal digits. Output may be used for operation of automatic typewriters, card punches, and tape punches. Designed for bench-top use, the instrument, designated the Type 33-110 " Sadic," requires no external power supply other than mains.

Input signals to the " Sadic " must be quasi-static in nature, i.e., they must remain constant long enough for the instrument to attain balance. Strain gauges, pressure pick-ups, load cells, position-measuring potentiometers, thermo-couples, analogue computers, and mass spectrometers are a few of the devices which may provide this type of signal. This analogue-to-digital converter operates on the self-balancing Thomson-Varley potentiometer principle and has 1000 discrete balance positions. It attains balance in a maximum of 0·8 sec. The converter measures approximately $9\frac{1}{2} \times 10 \times 18\frac{1}{2}$ in. Two units will fit side-by-side in a standard rack. It is also available with a drawer-slide mounting for use in data-processing systems.



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***Insulation? Protection? Silencing? Sealing?***

**Simple or complex, Redfern's will help to solve it. We have the experience, capacity and resources for economical bulk production of moulded components and extruded sections in natural and synthetic rubbers, and ebonite. Plan with all the knowledge of our technical staff at your elbow — we are always pleased to advise on the use of these versatile materials, and translate designers' ideas into terms of efficient production. Send us your enquiries—we will do the rest!**

**Literature is available describing our service — MOULDINGS . . . EXTRUDINGS . . . anti-corrosive LININGS & COVERINGS . . . FLOW FITTINGS (piping, cocks, tees, etc.,) . . . chemical-resisting UTENSILS . . . FABRICATED PARTS to specification.**

**A request to add your name to our mailing list will keep you up-to-date with publications dealing with any of these items.**

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***WILL HELP YOU SOLVE IT!***

MOULDINGS — EXTRUDINGS — FABRICATED PARTS AND UTENSILS

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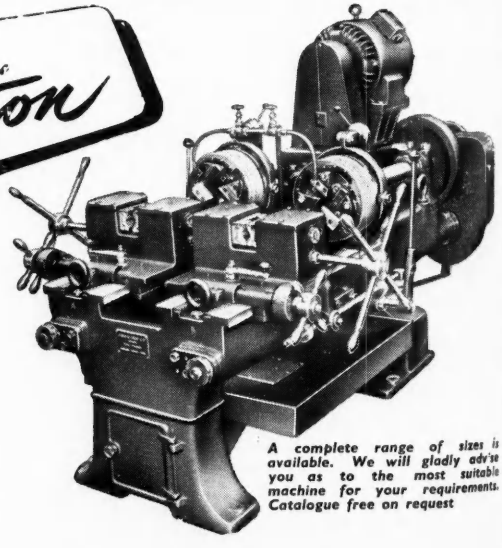


*A complete range of sizes is available. We will gladly advise you as to the most suitable machine for your requirements. Catalogue free on request*

## 2½" DOUBLE HEAD BOLT SCREWING MACHINES

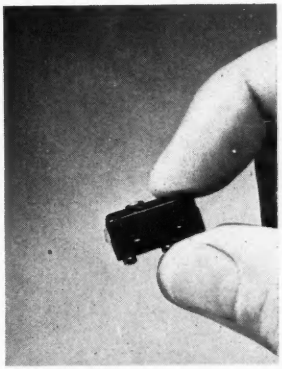
Designed for really high output the HEAP'S Automatic 2½ in. Bolt Screwing Machines will cut either right or left hand threads (or both at the same time). The machine is fitted with our potent TANGENTIAL Die Heads, which open automatically when any predetermined length has been threaded.

Capacity: Bolts up to 2¼ in. dia. pipes up to 2 in. dia. parallel or taper.

**JOSHUA HEAP & CO., LTD.**
**ASHTON-UNDER-LYNE • ENGLAND**

## SUB-MINIATURE MICROSWITCH

To meet the demand for even smaller microswitches, the Micro Switch Division of Burgess Products Company Ltd., of Team Valley, Gateshead, have produced a new model, the approximate overall dimensions of which are only $\frac{3}{4} \times \frac{1}{2} \times \frac{1}{4}$ in. Nevertheless, despite these reduced dimensions, the switch, which is robustly constructed and housed in bakelite, will break 5 A at 250 V a.c. or 2 A at 30 V d.c., and has a probable life of 50,000 operations.

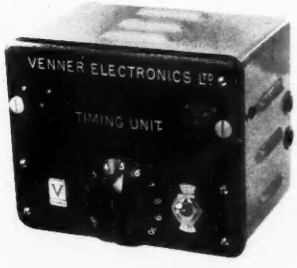


The switch is of the single-pole change-over type, with a positive snap action. Operation is effected by depressing a small bakelite plunger, a force of 7 oz maximum being required. For applications where it is not possible to apply the operating force at 90 deg. to the alignment of the switch, or when the actuating medium is a cam or a sliding dog, auxiliary actuators, with either plain levers or roller levers, are available.

## ELECTRONIC TIMING UNIT

Features of the new electronic timing unit introduced by Venner Electronics Limited, of New Malden, Surrey, include small size and the fact that it makes unit construction of timing equipment possible. It is believed that any time sequence involving individual times of five minutes or less can be met using the new timer, without making any wiring alterations to the instrument itself. This is accomplished by arranging that a momentary contact (made, for example, by a push-button) will start the timing period, changing over the single-pole contacts. At the end of this period the contacts change back and an output lead is momentarily short-circuited. This lead can be connected to the input of the next timer, and this will therefore start the second timing period.

This process can be repeated as many times as required and, if necessary, the pulse from the last unit may be passed back to the first, so that the chain will form a cyclic timer. A push-button can be provided, so that all the units can be returned to "safe," if desired. The time delays may run from fractions of a second to five minutes, it being inconvenient, but not impossible, to time longer periods. The electronic units may be combined with units driven by synchronous motors, to give long and short periods, as required.

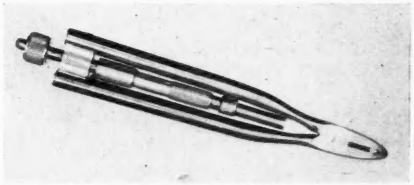



The timer is supplied with a terminal block for all external connections. A dial on the front of the instrument controls the time delay period, and this is normally supplied calibrated from 0 to 10, although individual calibration can be arranged. The repetitive accuracy of the unit is $\pm 2\%$ at midscale. Voltage or frequency variations in the mains supply have virtually no adverse effects on accuracy, except when such variations occur during an actual time cycle.

## WIRE-TWISTING TOOL

Originally manufactured in the U.S.A., where, as in other countries, it has had considerable success as a precision-engineered tool for twisting wire in the application of locking-wire of any gauge to connections on aero-engines, airframes, components, hydraulics, etc., the Robinson wire twister is now being manufactured in Great Britain by the sole concessionaires, Douglas Kane Associates, of London, S.W.1.

The Robinson wire twister has been designed and developed to twist wire speedily, neatly, and efficiently on jobs where this type of work is normally effected by hand or by pliers. In operation, the two ends of the wire are gripped by jaws, which are locked tight simply by sliding down a centre sleeve whilst squeezing the handles slightly. By pulling on the central spindle, the tool is then caused to spin, thereby twisting the wire evenly to any desired degree of twist. The jaws are



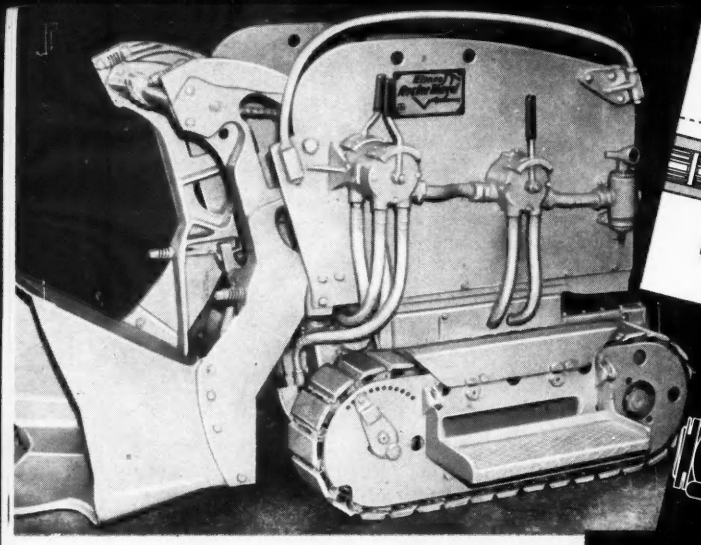
then opened again by a slight pressure on the handles, and the ends of the wire are cut off with the side-cutters incorporated in the plier head. The whole operation takes only two or three seconds—a fraction of the time normally required when the work is done by more conventional methods.

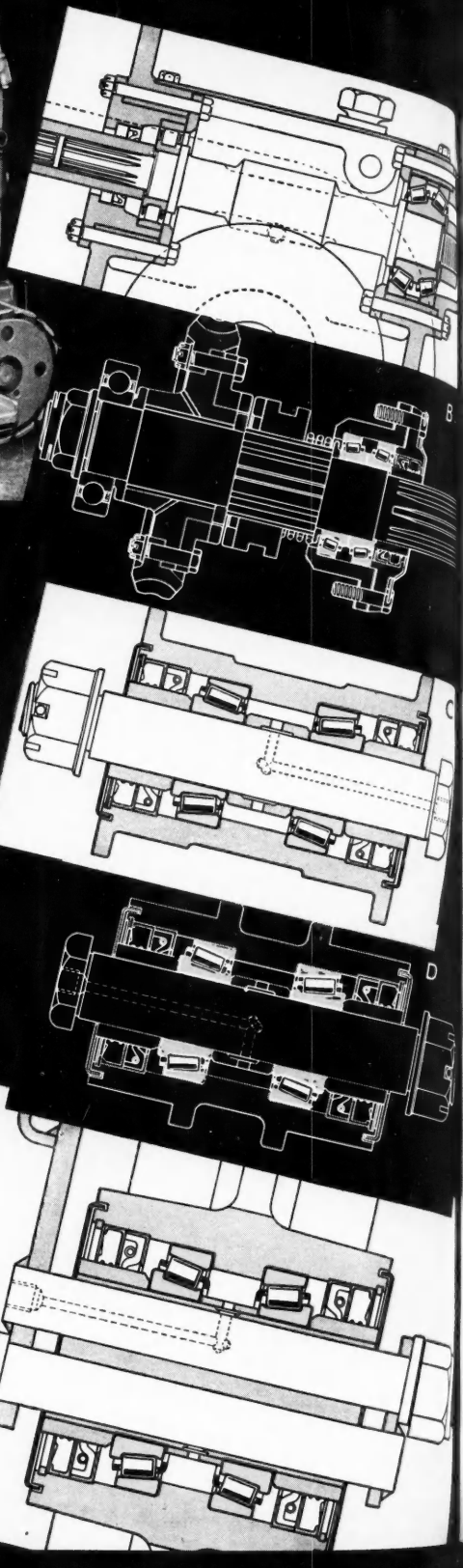
Bundling or coiling of wire, packaging of certain types, and baling or bag-tying can all be accomplished with this tool, and almost any type of locking-wire can be used. Three sizes, 9 in., 10 in., and 12 in. in length, are available.

## MOBILE RADIO-TELEPHONE

Designed to meet increasingly stringent performance requirements and specifications, the new "Ranger" dashboard-mounting mobile radio-telephone for 25 kc/s channelling, announced by Pye Limited, of Cambridge, is intended to work in either double or single frequency simplex on a press-to-talk basis, on channel spacings as close as 25 kc/s over its entire frequency range, thereby permitting the more efficient use of the available frequency bands and the allocation of many more frequency channels.

Additional features include exceptional frequency stability, high sensitivity and signal-to-noise ratio, robust construction, and small size. The standard version of the "Ranger" is for 6 to 12 V operation, with no muting incorporated. Special versions, however, include mute operation, up to 6-channel crystal switching, and public-address facilities.






## On the 'Eimco' RockerShovel

This interesting shovel, driven by compressed air, scoops a load and lifts it up and over into a container behind it, the operator standing on the low platform at the side. The machine is of very rugged construction and Timken tapered-roller bearings are extensively used.

The drawings on the right show some of the bearing installations.

A shows the wormshaft of the transmission, with a Timken double cone steep-angle bearing to meet heavy thrust from either direction, plus radial load.

B shows the worm-wheel shaft, with two adjacent Timken bearings which take the thrust from the wheel and carry the heavy radial loading from the sprocket. C and D show, respectively, the bottom and top track rollers, and E shows the front idler assembly: the ingenious support of the eccentrically mounted fixed spindle is interesting, also the careful provision for dirt-exclusion from the bearings.

In all, this machine is equipped with 34 Timken tapered-roller bearings.

MADE IN ENGLAND

**TIMKEN** Regd. Trade Mark: TIMKEN

*tapered-roller bearings*

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*Subsidiary Companies: Fischer Bearings Co. Ltd., Wolverhampton*
*Timken-Fischer Stockists Ltd., Birmingham*

# NEWS OF THE MONTH

## PERSONAL

**Mr. Donald C. Altman** has been appointed sales manager, Industries Group, of Allis-Chalmers (Great Britain) Ltd., Salisbury House, London Wall, E.C.2.

**Dr. A. M. Baxter, M.Sc.,** senior lecturer in the Department of Civil and Mechanical Engineering, Royal Technical College, Glasgow, has been appointed, as from December 1st, head of the Research Department of G. and J. Weir Ltd., Glasgow.

**Mr. J. W. Berry** has been appointed joint managing director of Birmingham Aluminium Casting (1903) Co. Ltd. **Mr. H. Goodwin** has been appointed joint managing director of Birmetals Ltd. **Mr. G. A. Rider** has been appointed commercial director of Birmingham Aluminium Casting (1903) Ltd. Both companies belong to Birmid Industries Ltd.

**Professor P. M. Blackett, F.R.S.,** of the Imperial College of Science and Technology, and **Mr. H. Douglas,** general secretary of the Iron & Steel Trades Confederation, have been appointed by the Lord President of the Council to be members of the Advisory Council for Scientific and Industrial Research.

**Commander (E) J. A. Blockley, R.N.(Rtd.),** has been appointed export sales manager of The Parsons Engineering Co. Ltd., Town Quay Works, Southampton.

**Mr. C. E. Blunt** and **Mr. J. A. Grace** have been elected to the Board of Folland Aircraft Ltd., Hamble, Southampton.

**Mr. H. W. Bosworth,** chairman of Lancashire Dynamo Holdings Ltd., St. Stephen's House, Victoria Embankment, London, S.W.1, will resign from this position at the end of the year, but will retain his seat on the Board of the company and his connection with the associated companies. He will be succeeded by **Sir Percy H. Mills, Bt., K.B.E.** The Minister of Fuel and Power has agreed to release **Mr. S. F. Steward, C.B.E.,** from his present position of chairman of the South Western Electricity Board at the end of the year, when he will take up appointment as managing director of Lancashire Dynamo Holdings Ltd. During the war Mr. Steward was Director of Industrial Electrical Equipment in the Ministry of Supply and later Director General of Machine Tools. He was chairman of the British Electrical Development Association in 1954.

**Mr. S. G. W. Cambers,** general manager, has been elected to the Board and has been appointed managing director of F.H. (Newcastle) Ltd., Pottery Lane, Newcastle-upon-Tyne, 1.

**Mr. J. Dent, A.M.I.Mech.E.,** has been appointed assistant chief engineer, Guided Weapons, with Short Brothers & Harland Ltd.

**Mr. E. Percy Edwards,** who has resigned from the Lapointe Machine Tool Co. Ltd., has joined the Catmur Machine Tool Corporation Ltd. as Birmingham area sales manager. He will operate from White House, 111 New Street, Birmingham, 2.

**Mr. J. P. Ford** has relinquished his post of managing director of the export companies of The Brush Group Ltd. in order to join the Board of Charles Colston Ltd. **Mr. M. C. Clear** will assume the office of managing director as from 1st November, in addition to his present office of sales director of The Brush Group. **Mr. G. N. Bridge** has been appointed London manager of the Brush export companies.

**Mr. Gordon G. Goodwin** has resigned from his position of publicity manager with The Sheepbridge Engineering Group to take up a new appointment as marketing manager with Tecalemit Ltd., Plymouth. He will be responsible to **Mr. G. E. Cater,** general sales manager, for marketing, sales promotion and publicity. **Mr. D. Emerson** has been appointed assistant marketing manager.

**Mr. A. W. Gosling, B.Sc.(Hons.), A.M.I.Mech.E.,** who recently resigned from the position of chief engineer with F. Perkins Ltd., has joined as chief engineer the Diesel Engine Division of Armstrong Siddeley Motors Ltd., Parkside, Coventry.

**Mr. Edward R. Hilton III, B.Sc.,** has been appointed assistant to the sales manager of the British Materials Handling Division, of The Yale & Towne Manufacturing Company, Wednesfield, Wolverhampton.

**Mr. E. M. Johnson** has relinquished his position as chief engineer of the Plant Department of Metropolitan-Vickers Electrical Co. Ltd., Trafford Park, Manchester 17, and has been appointed consultant to the chief electrical engineer of the company. **Mr. C. P. Holder, B.A., M.I.E.E.,** has been appointed chief engineer of the Large Electrical Machine Department, and **Mr. H. I. Wood, B.Sc., A.M.I.E.E.,** has been appointed assistant chief engineer of the Turbo-Generator Engineering Department.

**Mr. E. W. Kelleher** has been elected to the Board of B. Elliott & Co. Ltd., Victoria Works, London, N.W.10, and their subsidiary companies, the Cardiff Lathe & Tool Works Ltd., and Progress Drilling Machine Works Ltd.

**Mr. Fred Kendrick** has been elected a director of the Sheffield Forge and Rolling Mills Co. Ltd., Millsands, Sheffield.

**Mr. A. H. Kenyon, M.I.E.E.,** has been elected chairman of the North-Eastern Centre of the Institution of Electrical Engineers, in place of **Mr. D. E. Lambert,** who has resigned on assuming a new appointment.

**Dr. W. B. Littler** has been promoted Chief Scientific Officer and appointed Principal Director of Scientific Research (Defence), in succession to **Dr. Cawood,** who is to become Principal Director of Scientific Research (Air) on November 1st.

**Mr. R. J. S. Macpherson, M.I.Mech.E.,** chief engineer, has been appointed general manager of the Scottish Boiler and General Insurance Co. Ltd., 82 St. Vincent Street, Glasgow, C.2, in succession to **Mr. W. Wallace Kerr, M.I.Mech.E., M.I.E.E.,** who has retired after forty-two years in the company's service. **Mr. T. H. Dunsmoir, M.I.Mar.E.,** has been appointed chief engineer.

**Mr. Stuart Mitchell, M.Sc., A.R.T.C., A.M.I.C.E., M.I.Mech.E.,** has been appointed Group chief engineer of Associated British Engineering Ltd., 9-10 Cavendish Square, London, W.1. He will be responsible for the co-ordination of the technical activities of the six member companies of the Group and advising the Board on its technical policy.

**Mr. G. D. Mole, B.Sc.,** formerly personal assistant to the chief executive of Rolls-Royce Ltd., has joined Smiths Aircraft Instruments Ltd., Cricklewood, London, N.W.2, as project engineer (engines).

**Mr. A. S. Nicholas,** local director and general manager of the company's constructional works at Chepstow, Mon., has been elected to the Board of The Fairfield Shipbuilding and Engineering Co. Ltd., Govan, Glasgow.

**Mr. Orlando Oldham** and **Mr. Peter J. Brocklehurst** have been elected to the Board of Oldham & Son Ltd., Denton, Manchester.

**Mr. F. Pickworth,** managing director of English Steel Corporation Ltd., has been elected chairman of the Board, in succession to **Lt.-General Sir Ronald Weeks, K.C.B., C.B.E., D.S.O., M.C., T.D.,** chairman of Vickers Ltd. Mr. Pickworth has also been elected to the Board of Vickers Ltd. **Mr. W. D. Pugh** has been appointed managing director of English Steel Corporation Ltd., in succession to **Mr. Pickworth.**


**THE RECIPROCATING TOGGLE THEN ACTUATES THE PLUNGER IMPELLER**

It's as clear as that, except for endless modifications and sleepless nights sorting out production difficulties. The spring part can be left to Lewis, of course. That has become a habit in the last thirty-five years.

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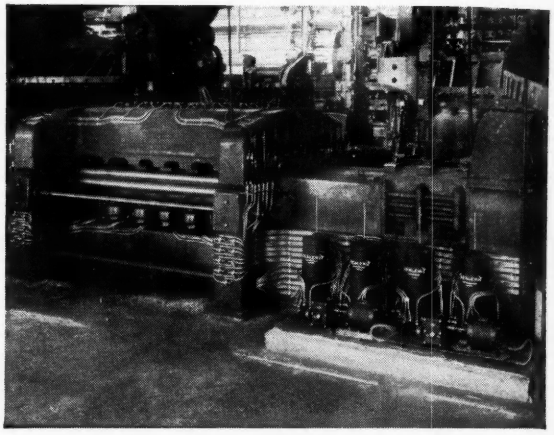
# Drum to bearing lubrication shuts out abrasives



**Four mechanised 'Radial' Grease pumps fitted to an UNGERER flattening press at the Austin Motor Co. Ltd. (acknowledgements to Austin Motor Co. Ltd.)**

**The 'Radial' used on a Rubber Compressing machine (acknowledgements to Expanded Rubber Co. Ltd.)**

Where machines are working in dirty conditions, ordinary lubrication methods can actually have an opposite effect by forcing grease contaminated with abrasive particles into the bearings.

The surest way to avoid this danger, is by installing the Tecalemit 'Radial' Grease Pump. This compact, force-feed lubricating unit is for use with grease that collapses under its own weight. It carries up to a maximum of 19 pump units and lubrication lines, one for each bearing. Each of these pump units has adjustment washers by which the amount of grease delivered at each stroke can be predetermined; settings are possible from ·007 c.c. to ·205 c.c. per shot.

The 'Radial' System is rotary driven anti-clockwise or clockwise from machinery, or from its own motor with reduction gear box assembly.

Filled with the Tecalemit Gun Filler Attachment, the 'Radial' Pump obviates all chance of the grease being contaminated. It supplies lubricant direct from drum to bearing without exposure to the air.

**PRODUCTION COSTS CUT**

So machinery is assured of regular, correct and *clean* lubrication — a certain way to cut breakdowns and prolong the machine's working life.

The 'Radial' is one of the wide range of lubrication systems produced by Tecalemit and used throughout industry.

A Tecalemit technical representative will be glad to give you full details of installation and methods of ordering.

**TECALEMIT**
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**Mr. G. A. Plummer, M.I.Mech.E., M.I.Mar.E., M.A.S.M.E.,** has been elected to the main Board of John Thompson Ltd., Ettingshall, Wolverhampton. He will continue as a director and chief engineer of John Thompson Water Tube Boilers Ltd. and in his capacity in connection with the company's nuclear power projects.

**Mr. F. A. Pope** has been elected to the Board of John Bull Rubber Co. Ltd. **Mr. M. Goldsmith** has been elected deputy chairman and joint managing director, and **Mr. S. Perrin** has been appointed joint managing director of the company.

**Mr. J. T. Sharples, B.Sc., A.M.I.E.E.,** has been appointed manager of the main plant of Barlow-Whitney Ltd., Bletchley, Buckinghamshire.

**Sir Eric Bourne Bentink Speed, K.C.B., K.B.E., M.C.,** has been elected to the Board of Engelhard Industries Ltd., 52 High Holborn, London, W.C.1.

**Mr. G. S. Sutcliffe,** sales director, has been appointed managing director of Ferodo Ltd., Chapel-en-le-Frith, in succession to **Mr. William Smith,** who will remain, however, on the Board until his retirement on December 31st. **Mr. E. R. Pochin,** home sales manager, has been elected to the Board as home sales director.

**Mr. Maurice Tattersfield,** director and general manager of Brush Electrical Engineering Co. Ltd., Loughborough, has been appointed managing director of the company.

**Mr. John Taysom** has been appointed works director of Cimex-Fraser Tuson Ltd., Orpington, Kent.

**Mr. Walter Titmus** has been appointed manager of the Industrial Controls Division of the Solarton Electronic Group Ltd., Thames Ditton, Surrey.

**Mr. A. Walsh, Assoc.M.C.T., M.I.E.E.,** has been appointed consulting engineer (patents) of Metropolitan-Vickers Electrical Co. Ltd., Trafford Park, Manchester, 17, to succeed **Mr. L. H. A. Carr,** who has retired. **Mr. S. Andrew** has been appointed assistant superintendent of the Transformer Department.

**Mr. T. E. Wilson, A.M.I.E.E.,** has been appointed assistant (electric traction and generation) to the chief mechanical and electrical engineer, British Railways, London Midland Region, Derby.

**Mr. A. E. A. Wright** has been elected a director of Prior Stokers Ltd., 1/3 Brandon Road, London, N.7, and of Sheet Metal Specialities Ltd.

## FUEL EFFICIENCY EXHIBITION

Organized by Provincial Exhibitions Limited, the Fuel Efficiency Exhibition was officially opened on October 12 by Sir Miles Thomas, D.F.C., M.I.Mech.E., Chairman of the British Overseas Airways Corporation.

A record number of almost one hundred firms effectively demonstrated solid- and liquid-fuel economy for all branches of industry. In addition, for the first time, atomic energy has found a place in this Exhibition, as was demonstrated by the U.K. Atomic Energy Authority, who showed the vast strides already made towards the industrial application of nuclear power, and by the Central Electricity Authority, who indicated how the newest methods of fuel efficiency are applied in the generation of power.

## NORTON GRINDING WHEEL CO. LTD. EXPANSION PROGRAMME

Coincident with the 25th anniversary of Norton Grinding Wheel Co. Ltd., the Company has announced a £500,000 expansion programme over the next three years, involving large-scale additions to the factory and new offices. This programme will provide increased factory space, resulting in a more efficient plant. This will not only give increased production facilities, but will also enable an even wider range of products to be manufactured, including refractory products for atomic-energy work.

At present, the Company produces an extremely wide range of grinding wheels, both in specification and size, from ⅛ in. diameter and a fraction of an ounce in weight to 72 in. across and weighing over 2 tons. These large segmental wheels may be 18 in. in thickness, while, on the other hand, there are also cut-off wheels only 1/64 in. in thickness. In addition to straight wheels, large numbers are made to various shapes—tapered, cupped, and bevelled—for all types of specialized work; finally, there are many other abrasive products other than wheels, such as rubbing bricks and sticks, hones, oilstones, and sharpening stones, all of which are produced at the Company's factory in Welwyn Garden City.

## JOHN BOOTH & SONS (BOLTON) LTD. GOLDEN JUBILEE

Although John Booth & Sons (Bolton) Ltd. celebrated this month the Golden Jubilee of the official opening of Hulton Steelworks, the completion of this enterprise in 1905 did not signify that an entirely new business was ready to start work in Bolton. On the contrary, the firm of John Booth & Sons was already a well-established, flourishing concern, with more than twenty years of steadily expanding business behind it.

Actually, it was in 1873 that John Booth opened his own business as Engine and Machine Smith at premises in Mill Brow, Bolton. Nine years later, when more space was urgently needed, he took over the buildings, now known as the Marsden Road Ironworks, consisting at that time of a mill and some adjacent property. In this connection, it is interesting to note that it was in this mill that Samuel Crompton, the inventor of the spinning mule, first began to spin cotton as a commercial project.

The business continued to thrive at Marsden Road but it soon became apparent that a new site, with access to the railway, would have to be found. In 1904 a suitable 10-acre site was obtained, and work was immediately started on a two-bay factory, 300 ft long by 80 ft wide, which was completed in the following year. From then onwards, the story of John Booth & Sons is one of continued success and expansion, which included the development of the North-Light Warren Girder Roof and its widespread application to the textile and other industries. Further factory bays and office buildings were added as the need arose and, by the time World War I started, factory space had more than doubled to 56,100 sq ft. In 1917 it again became apparent that additional manufacturing space was required, and two more bays, a fitting shop, stores, and a permanent canteen were added, bringing the total floor space up to 107,200 sq ft. To-day, three of the existing bays are being given an increase in floor space of 16,000 sq ft, bringing the total area of the works, offices, stock-yards, and railway sidings to well over 20 acres.

## SCIENCE AND MANAGEMENT

The British Institute of Management published the advance programme of its National Conference to be held this year at Harrogate from 2nd to 4th November. The Conference will have as its theme "The Impact of Science on Management in the Future."

The Conference is intended to serve as a platform from which those concerned with the application of science to industry, commerce and local government may disseminate news of the most up-to-date developments. At the same time it will provide an opportunity for a thoroughgoing exchange of information between those managers attending. Stress will be laid throughout the Conference on the need to translate new scientific discoveries into immediate and practical day-to-day effect. Each delegate will bring his own experience to bear on the subjects to be discussed.

"Automation" is only one of the new techniques which will form the subject of a sectional meeting. Other subjects include the uses of radio-active isotopes and the electronic processing of data, while a panel representing scientists in industry will discuss changes brought about by recently developed materials and processes. The application of scientific techniques to retailing and market analysis will be studied at the Conference and the contributions of such sciences as sociology and economics will also have an important part to play. Special attention will be paid to the human aspects of technological progress and to the problems of training managers to meet the needs of the future.

Out of twenty-four sectional meetings to be held in the course of two days one-third will take the form of panel discussions at which experts in particular fields will shed light on different aspects of a common problem. Where meetings are to be addressed by a


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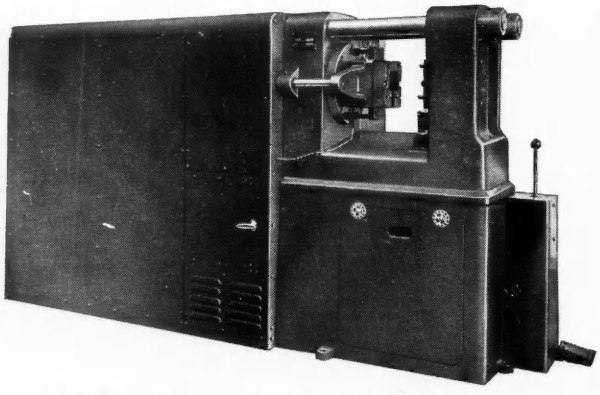

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● **OUTSTANDING FEATURES . . . .**

Greatly increased output, Perfect control, Increased holding power, Higher injection pressure, Streamlined power unit, Automatic shut-down in the event of a pressure drop in the hydraulic system stopping motor and pump and isolating high pressure nitrogen cylinder, New valve block, Accessible oil filter.

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Here's a Spearseg saw really getting its teeth into the job . . . cutting Cutlery quality Stainless Steel at the works of **BROWN BAYLEY STEELS** Ltd., Sheffield. This is the kind of work in which a Spearseg excels. Designed to give fast and accurate working, its characteristic properties of toughness and hard wear ensure a long, trouble-free life. The Spearseg saw can be resharpened many times before individual segments need be replaced.

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*High Speed SEGMENTAL SAWS*

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single speaker, the text of the paper will in most cases be circulated beforehand; the speaker will then confine himself to delivering a summary of his conclusions so that discussion may begin as soon as possible. On Thursday evening, November 3rd, delegates will have a choice of sixteen discussion groups, each devoted to a topic currently attracting widespread attention in management circles. Provision is being made for 1,000 top managers to be received in Harrogate as delegates to the Conference.

## BUSINESS NOTES

**Norris Industrial Consultants Ltd.,** 3 Unity Street, Bristol, 1, have established a research and development department which will undertake the computation of complex stress factors, development and analysis of industrial processes and equipment for improved productivity.

**The Square D Company,** of Detroit, U.S.A., announce the formation of a British subsidiary company, Square D Ltd., with headquarters at 100 Aldersgate Street, London, E.C.1, with branch offices to be established in provincial centres. Selected export markets will also be served. Motor control items from the company's American range will be manufactured by The Plessey Co. Ltd. Mr. F. W. Magin, President of the parent company, Mr. F. H. Roby, Mr. J. F. Magin, from the U.S.A., and Mr. B. C. Spicer and Mr. R. P. Chambers, from the U.K., are directors of Square D Ltd.

**B. O. Morris Ltd.,** Coventry, have concluded an agreement with Hammond Machinery Builders Ltd., Kalamazoo, Michigan, U.S.A., for the manufacture of their automatic and semi-automatic polishing equipment, including rotary and straight line machines, under licence in this country. Production of this range of machines has already commenced.

**Crawford & Co. (Tottenham) Ltd.** have changed the name of the company to Crawford Collets Ltd.

**Misal Soc. Acc. Leto,** Via Vittor Pisani 14, Milan, Italy, have been appointed sole agents for the Canavese range of lathes manufactured by Eredi G. Canavese, of Crema, Italy.

**Serck Radiators Limited** and **Serck Tubes Limited** have together opened new offices at 16, Berkeley Street, London, W.1 (telephone Mayfair 9744). This is to serve the interests of both main manufacturing companies in Birmingham.

Lieut.-Cdr. (E) A. W. M. Collyer, R.N.(Ret'd), represents the Engineering Division of the group which produces a very wide range of heat exchange equipment.

Mr. A. List-Brain, coming to the Serck organization from the Brightside Foundry and Engineering Company, is available as a technical consultant on the range of high-duty non-ferrous tubes for petroleum refineries and main steam condensers in which, with their new tube mill coming into full production, Serck Tubes Limited are specializing. Mr. List-Brain, who was a student apprentice with Babcock & Wilcox Limited, served the Anglo-Iranian Oil Company as a process engineer in the Middle East.

London area service for the motor industry for radiator, lamp, grille and bumper repairs is provided by the Serck London Branch factory at Park Royal (telephone Elgar 6041).

**The Mission Manufacturing Company,** Houston, Texas, have decided to establish an undertaking in Northern Ireland for the manufacture of oilfield equipment. A Government factory for the project will shortly be erected on Site 13 on the industrial estate at Castlereagh, Belfast, and, pending the completion of the factory, it is proposed to commence operations in an unoccupied part of the Hughes Tool Factory.

The Mission Manufacturing Company are oil specialists who have been in business since 1925 and are the leading manufacturers in the world of oilfield slush pump parts. It is planned to provide employment at Castlereagh for about 70 persons, almost all of whom will be men, and there is the possibility of increasing the labour force at a later stage by producing other items of oilfield equipment not at present manufactured by the company.

Virtually the whole production of the factory will be exported, and it is expected that the principal markets will be in South America, India, Pakistan and the Middle East.

The Hughes Tool Company, who are already in production in one of the Ministry of Commerce factories at Castlereagh, also have their headquarters at Houston, Texas.

**Redferns (Bredbury) Ltd.,** a subsidiary company of Redfern's Rubber Works Ltd. of Hyde, Cheshire, have now commenced trading as a separate entity at Bredbury, nr. Stockport. The telephone number is Woodley 2687.

The Bredbury works were established in August, 1954, when a production unit of the Mechanicals Division of the parent company moved from Hyde to more extensive premises at Bredbury. Existing plant has been re-planned and supplemented by additional equipment so that production facilities are greatly extended.

Redferns (Bredbury) Ltd. specialise in the lining and covering of chemical plant with corrosion-resistant rubber and ebonite; roller coverings; tank linings; chemical-resisting utensils; and fabricated parts in natural and synthetic rubber and ebonite.

**The Society of Industrial Radiology and Allied Methods of Non-Destructive Testing** commences its winter programme during October.

This Society, which was founded at the close of last year, and now has a membership of over 200, is the first professional body in this country endeavouring to co-ordinate all specialists employed in the various methods of non-destructive testing.

Its chief concern is to establish and maintain a high standard of technical practice and to facilitate the exchange of information and ideas on matters concerning these rapidly expanding methods of inspection. With these objects in view a programme of monthly meetings has been arranged by the branches of the Society at London, Birmingham, Sheffield and Glasgow.

Particulars are obtainable from the Honorary Secretary, Mr. D. N. Laurie, 2 Tomswood Terrace, Barkingside, Essex.

## CONTRACTS

The Bold "A" generating station of the Central Electricity Authority (North-West, Merseyside and North Wales Division) will have a total output capacity of 120 MW supplied by four **Metropolitan-Vickers** 30-MW steam turbine-generators, of which the first two are already installed.

The Metropolitan-Vickers turbines, two-cylinder machines, are designed to run at 3000 rpm with inlet steam conditions of 600 psig, 850° F. Four-stage feed-heating is employed, giving a final feed water temperature of 345° F at 30 MW maximum continuous rating.

The generators are direct coupled to the turbines, and are each rated at an output of 37,500 kVA at 11·8 kV three phrase 50 cycles. They are air-cooled, and conform to the Metropolitan-Vickers standard for this size of machine.

Further Metropolitan-Vickers equipment includes transformers and boiler auxiliary equipment. The two transformers already installed are 36-MVA generator transformers having a voltage ratio of 11·8/35·4 kV, and fitted with on-load tap-changing equipment for high voltage variation from $+7\frac{1}{2}\%$ to $-7\frac{1}{2}\%$ of nominal voltage in 10 steps.

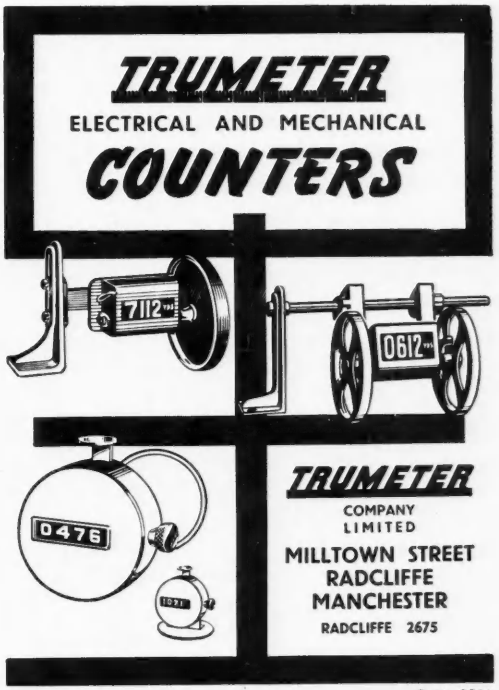
Boiler auxiliary equipment supplied includes thirty-six Metropolitan-Vickers motors, ranging from $1\frac{1}{2}$-hp to 240-hp, for various duties, including drives for pulveriser mills, exhauster fans, induced draught fans, forced draught fans and separators.

**The General Electric Co. Ltd.** has received an order for a 4500-kW pass-out turbo-alternator set from the Westfield Paper Co. Ltd., Bathgate, West Lothian. The 3000-rpm direct-coupled machine will be provided with a Hick Hargreaves surface condensing plant. The alternator is of the closed ventilated type, generating at 3300 volts, and designed for operation with a power factor of 0·8.

The consulting engineers for the installation are J. D. Crozier & Partners Limited, of London and Edinburgh.

**Ferranti Ltd.** have been awarded a further order by the Aluminum Company of Canada Ltd., for three 71,000 kVA, single-phase generator transformers stepping up to 301,400 volts.

These units will form the second 213,000 kVA bank of generator transformers to be supplied by Ferranti Ltd. for installation in the now famous "Power Station inside a mountain" of the Alcan Project at Kemano, British Columbia. The transformers are

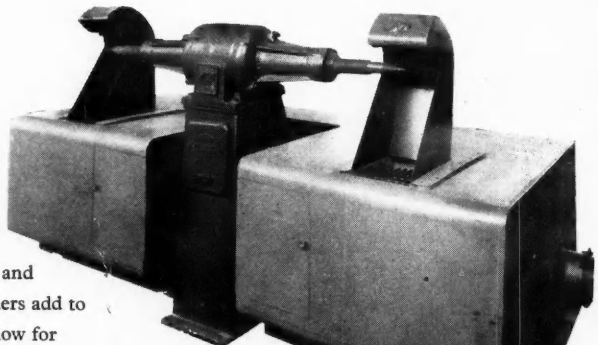



C.W. 2864

GRIFFITHS
the SATISFACTORY PLANT

# Polishing Efficiency

These units can be added to, giving a continuous bench appearance, if desired. Note the strong hoods and ample adjustment that is provided. The clean pleasing lines of the steel table, giving a clear area for component storage. Flush doors to operator's cupboards and the absence of ledges and sharp corners add to personal safety. Install these units now for universal satisfaction from your Polishing Department.



GRIFFITHS
the SATISFACTORY PLANT

**A. E. GRIFFITHS (SMETHWICK) LTD.**
**BOOTH STREET, BIRMINGHAM, 21**
**Phone: SMEthwick 1571-2-3-4-5, Grams: Grifoven, Smethwick.**

A.E.G. Pub.

Production of this clevis pin under Lang control was doubled with half the labour used on manual operation of machinery.

**LANG PNEUMATIC CONTROL EQUIPMENT**
***entirely non-corrodible***

Every part of Lang Pneumatic equipment is produced from stainless steel or non-ferrous metals. They are entirely non-corrodible and are thus fitted for heavy, continuous operation under arduous conditions. Lang Pneumatic Controls are installed in the majority of leading industrial concerns—affording simplicity in complex operations, high speed precision control, and the fullest use of semi-skilled labour.

*Plan with*
**LANG PNEUMATIC LTD**
VICTORY WORKS BIRMINGHAM ROAD WOLVERHAMPTON Tel: 25221-2-3

unique in that they will have aluminium windings, and it is believed that they will form the largest bank of transformers with aluminium windings in the world.

This order brings the total number of transformers supplied or under construction by Ferranti Ltd. for the Alcan Project to 13 units of a total capacity of 648,000 kVA.

For the newly completed cardboard manufacturing factory of South African Board Mills Ltd. in the Transvaal, **Crompton Parkinson Ltd.** supplied a Ward Leonard set comprising an auto-synchronous a.c. motor direct coupled to a d.c. generator which in turn controls the 240-hp main motor. The Ward Leonard system was necessary to achieve the high degree of control required and in fact gave a 6 : 1 speed range. The main motor drives direct the line shaft, from which plant in the various sections of the factory are belt-driven. Coned pulleys are employed to provide fine adjustment facilities for the relative speeds of different items of plant.

The auto-synchronous motor of the motor-generator set is designed to run at 0·8 leading power factor, thus enabling the overall power factor of the factory to be maintained at an efficient and economical level.

Remote control for the motor-generator set is provided, fully automatic control gear being installed in the motor room, and facilities have also been provided for automatic dynamic braking of the plant when the main motor is switched off.

In addition to this main drive equipment Crompton Parkinson Ltd. also supplied numerous motors for individually driven auxiliary plant.

**Marconi Instruments Ltd.,** in conjunction with Svenska Radioaktiebogalet, have been successful in obtaining a £23,000 contract for Signal Generators from the Royal Swedish Air Board. The contract was secured in the face of severe competition, especially from American organizations—both as regards price and delivery dates.

In the first place, great interest was aroused by the existing generator Type TF 801B but, eventually, a special model—Type TF 801B/1—was developed to meet the detailed requirements of the Air Board. Covering a range of 12 to 425 mc/s, the new amplitude-modulated generator has a calibration accuracy of 0·5% and has the particular merit that spurious frequency modulation is virtually non-existent—an essential requirement of the Air Board specification.

Against very severe foreign competition, principally from Germany, **Davy and United Engineering Company Limited** of Sheffield have just secured a contract worth close on £300,000 to build a new hot strip mill plant for Surahammars Bruks A.B., of Surahammar, Sweden.

The new mill, a 60" wide 4-high reversing unit which will need an 8000-hp motor to drive it, is being designed specially for the hot rolling of alloy steel strip. It will operate in conjunction with an existing roughing mill and new coiling furnaces in which the strip will be maintained at rolling heat, a system ideally suitable for alloy steel rolling.

# Classified Advertisements

*The rate for all classified advertisements is 6d. per word; in bold print 9d. per word; minimum order 6s. Box-number advertisements 1s. extra. Instructions, together with remittance, must be received not later than the 3rd of each month for advertisements to appear in the same month's issue.*

## SITUATIONS VACANT

The Wolverhampton branch of a world-wide industrial organisation offers permanent positions with excellent prospects of promotion for both senior and junior staff as **TECHNICIANS** and **DESIGN AND DETAIL DRAUGHTSMEN** on interesting design and development work in connection with atomic energy, aircraft, guided weapons and industrial engineering projects.

**TECHNICIANS :** Engineering or Mathematics degree preferred—minimum acceptable qualification Higher National Certificate, engineering standard; for junior positions in this category, engineering experience is not essential.

**DESIGN AND DETAIL DRAUGHTSMEN :** Higher National Certificate in engineering preferred—this may be waived for designers with worthwhile experience in mechanical engineering; for junior positions in this category applicants studying for Ordinary National Certificate/Higher National Certificate in mechanical engineering will be considered.

Dependent upon suitable experience and qualifications, salary scales range to approximately £1,250 per annum for Technicians, £900 for Design Draughtsmen, and £750 for Detail Draughtsmen. Candidates possessing a particularly high potentiality will be eligible for higher salary levels than those quoted.
Company employee schemes and excellent working conditions generally include superannuation scheme, a profit-sharing scheme, a 5-day 40-hour week and good Canteen and Sports Club facilities. Travel and other incidental expenses will be defrayed by the Company for selected candidates called for interview.
Replies should be addressed to Box No. 41.

**IMPERIAL CHEMICAL INDUSTRIES LIMITED**
METALS DIVISION,

one of the largest producers of non-ferrous metals and the principal producer of Titanium in the United Kingdom, has vacant a number of interesting and responsible posts carrying attractive financial and other prospects. These vacancies are for technical personnel in the Research, Engineering and Production Departments, and are mainly in the Midlands although there are others of particular interest to Metallurgists and Mechanical Engineers at Liverpool.

Applications are invited for :

**TECHNICAL OFFICERS :** Candidates should be honours graduates, or equivalent, in Metallurgy, Physics and Mechanical or Electrical Engineering.

**ASSISTANT TECHNICAL OFFICERS :** This description includes other scientific staff who possess technical knowledge and/or experience in the fields of Metallurgy, Chemistry, Physics and Engineering.

**LABORATORY ASSISTANTS :** Young men and women between the ages of 16 and 22 interested in either Metallurgy, Chemistry or Physics, with the minimum qualification of a good General Certificate of Education at Ordinary Level are required. Facilities for further education are available.

All these posts are permanent and employees over the age of 20 join the Pension Scheme and qualify after two years' service for inclusion in the Company's Profit Sharing Scheme. Excellent Canteen facilities are available. Consideration will be given to assisting with removal expenses of married men. Out of pocket expenses are paid to applicants invited for interview.

Application forms may be obtained from **Staff Manager, I.C.I. Metals Division, Kynoch Works, Witton, Birmingham 6,** quoting reference GEN/2.

**GLACIER METAL COMPANY LIMITED**
**VACANCIES**

Applications are invited for a limited number of Vacancies which have occurred through expansion of our Technical Organisation and promotion within the Company. Vacancies are at Wembley unless otherwise stated.

**MECHANICAL ENGINEER.** Interesting position for man able to work on own initiative for about six months at a time carrying out research projects into the relationship between the conditions under which plain bearings operate and their dimensional and lubrication requirements; preparing from results design procedures for routine use by others. Desirable qualifications include engineering knowledge to level of 2nd Class Hons. Degree, and some workshop experience. More complex projects are planned the successful completion of which will carry a higher salary. Work is customer oriented research and offers good experience for career aiming either towards the research and development or sales fields.

**SENIOR DEVELOPMENT ENGINEER** to take charge of research design and development of Centrifugal Filters. This post is at Glasgow. The appointee will have full management responsibility for two subordinates, and will himself be accountable to the Chief Research Engineer at Wembley; consequently, it is essential that he is able to work without frequent instruction and guidance. Essential qualifications include 1st or 2nd Class Hons. Degree in engineering and an apprenticeship.

**DEVELOPMENT ENGINEER** to design and develop equipment for research into the operation of plain bearings. His instructions will specify the kind of experimental information required and he will have to decide the type, size and construction of equipment and what methods of measurement to use. He will need to seek information from the literature, and by his own research, about particular dimensional measurements which require new techniques. He will have a designer responsible to him. Essential qualifications include 1st or 2nd Class Hons. Degree in engineering and an apprenticeship.

**STATISTICIAN** required for work on the design of experiments, quality control and general statistical investigations. Good fundamental knowledge of statistics necessary but detailed experience in fields of experimental design and quality control is not essential as training can be given in special techniques employed by Company. University Degree or A.I.S. essential.

**RESEARCH ASSISTANT** required for work of experimental nature. Candidates must hold Licenciateship of Institution of Metallurgists or Higher National Certificate in Metallurgy or be at an advanced stage of study for either of these. Previous experience in laboratory work essential, and experience of research work desirable.

All these vacancies provide scope for advancement and offer salaries commensurate with positions, qualifications and experience. For further more detailed information apply Personnel Manager, Glacier Metal Co. Ltd., Ealing Road, Alperton, Wembley, Middlesex.

**REPRESENTATIVE (35/40)** required to sell non-ferrous centrifugal castings. Engineering training or background required. Must be able negotiate at high level. Good remuneration and prospects for first class man. Write **Metals & Alloys,** Minworth, Birmingham.

## BEARINGS

**BALL & ROLLER BEARINGS.**—All Types and Sizes, Largest Stocks, Lowest Prices. Same day dispatch. **895-921 Fulham Rd., London, S.W.6.** Renown 6174 (Ext. 24).

## BOOKS RECEIVED

**Capstan and Turret Lathe Practice.** By C. Monday. 199 pp., 231 illustrations. Publishers: The Machinery Publishing Co. Ltd., National House, West Street, Brighton 1. Price: 17/6.

Capstan and turret lathes occupy an important place in modern machine-shops and are used to a large extent for components formerly turned on centre lathes. This useful book covers the subject of capstan and turret lathes concisely and clearly, both insofar as their construction and application are concerned.

The book, a worthy addition to *Machinery's* Standard Reference Series, includes chapters on Types and General Construction of Capstan and Turret Lathes; Chucks, Workholders and Adapters; Cutting Tools; Turning and Facing; Drilling, Boring and Reaming; Thread Cutting; and Tooling and Setting-Up Examples. Printing is of a high standard and the book is enlivened by a wealth of excellent illustrations.

**The Gas Turbine Manual.** 2nd Edition, 1955. By R. J. Welsh, Wh. Ex., M.I.Mech.E., M.I.Mar.E., M.N.E.C.Inst.E. & S., and Geoffrey Waller. 304 pp., 151 illustrations. Publishers:—Temple Press Limited, Bowling Green Lane, London, E.C.1. Price:—30/-.

Since the first edition of this interesting book appeared in 1951, the gas-turbine industry has continued to develop rapidly. This second edition has, therefore, a much more comprehensive background of technical developments, necessitating extensive revisions to be made. The result is a valuable guide to current gas-turbine practice, excluding only the field of aircraft propulsion.

In addition to descriptions and illustrations or numerous installations for power stations, ships, locomotives, cars, and industrial purposes, particulars are given of something like 100 gas-turbine designs from ten different countries, together with reference chapters including a directory of the British and foreign gas-turbine industries, useful conversion tables, a glossary of gas-turbine terms, and a comprehensive bibliography. In addition, specifications of modern British gas turbines, in ascending order of power output from 30 to 25,000 bhp, are given.

## LATEST INDUSTRIAL LITERATURE

**1. Rigid Thermoplastic Materials.** A new, high-tensile, high impact-strength, rigid thermoplastic, with many outstanding properties, is described in an illustrated 4-page brochure. This new material is stated to have remarkable strength, durability, and toughness, far exceeding that of any thermoplastic available in quantity production. It closely approaches commercial aluminium in its tensile, shear, and impact strength and has, therefore, a very wide range of applications for high-duty components in which other types of rigid plastic fail.

This material can be moulded, extruded, machined, threaded, formed, welded, and bonded to itself or to metals. Furthermore, its dielectric properties make it eminently suitable as a non-conducting substitute for non-ferrous metals.

**2. Protective Coatings and Refractories.** In a well-produced and illustrated 6-page pamphlet, details are given of a comprehensive range of protective coatings and refractories, including acid-resisting cements, metal-spraying and bitumen-spraying processes, anti-abrasive linings, and corrosion-resistant industrial paints. Details are also given of a protective lining or coating for metal tanks, containers, filter plates, etc., giving a chemically inert, non-staining, sterile, and completely smooth finish, and ideally suitable for bulk-storage vessels or transport tanks for milk, beer, wines, fruit-juices, etc.

Also described is a synthetic coating specially suitable for the protection of racks and jigs in the plating industry, and a range of floor tiles, flooring materials, and decorative wall surfaces.

**3. Electric Heating and Lagging Units for Pipes and Columns.** Details are contained in a 4-page brochure of a range of electric heating and lagging units for pipes and columns. These units consist of flexible heating panels, woven from glass yarn, and insulated electric heating elements backed by from 1½ to 3 in. of glass wool for thermal insulation and enclosed by cylindrical stove-enamelled sheet-metal casings. This robust heating unit is hinged for easy application and is fastened by spring toggles but, for larger dimensions, it is also made in two separate semi-cylindrical sections which are bolted together.

The standard units are suitable for temperatures up to 750° F. Terminal boxes are fitted to the metal enclosure and provide for ¾-in. conduit entry on units up to 30 A loading and 1-in. conduit entry for higher powers. The heating elements can be split up into several circuits up to 2500 W each, and either lateral or vertical heat gradients can be provided.

**4. Wheels and Castors.** A well-produced and illustrated 24-page catalogue gives full details of a comprehensive range of wheels and castors for all classes of industry, together with indications of different arrangements of wheels and castors for various loading and other conditions.

Types of wheels and castors featured include cast-iron rubber-tyred roller-bearing and plain-bore wheels, flanged wheels, combined radial- and thrust-bearing types of castors, malleable heavy-duty castors, and twin-wheel castors. Also listed is a range of axle brackets and collars, round and square axles, ball thrust bearings, and wheel locking devices.

**5. Humidity Instruments.** In a neatly produced and illustrated 6-page brochure details are given of a range of instruments for indicating, recording, and regulating humidity and/or temperature, suitable for most applications where humidity measurement or control is required.

A typical example is a direct-reading, self-contained combined temperature and humidity recorder. This instrument is fitted with two pens, one for the direct recording of relative humidity and the other for temperature as measured by a mercury-in-steel system. No water supply is required, humidity being measured directly by a simple and reliable method. The range of this instrument is from 20 to 100% relative humidity and 20 to 100° F or 0 to 40° C. An alternative instrument, employing a humidity element capable of operating an electrical recorder, is also available.

**6. Chemical and Industrial Stoneware Plant and Containers.** A representative range for chemical stoneware is described and illustrated in an interesting 24-page catalogue. This stoneware is proof against attack from all corrosive agents, with the exception of hydrofluoric acid and hot, strong caustic alkalis. Whether the ware is glazed or unglazed is, of course, immaterial, as the body itself is corrosion-proof right through.

Most of the articles described are normally manufactured from a standard chemical stoneware, finished with a cream glaze, except in the case of absorption towers and large vessels of over 100 gallons capacity, which are usually brown-glazed. For use in the pharmaceutical, food and drink, cosmetic, photographic, and various other industries, a white porcellaneous ware is available in most patterns. Shapes and sizes of plant and containers for special purposes can be designed to meet individual requirements.

**7. Charging Machines for Heat-Treatment Furnaces.** Details are given in an illustrated 4-page brochure of a wide range of charging and discharging machines for all types of heat-treatment furnaces, including turntable types and with from two to six arms.

The charging arms are of the expanding type, rolling in slots in the furnace hearth, thereby avoiding any cantilever action and permitting the handling of loads up to 40 tons, if required. Furthermore, the charge and discharge of the furnace is carried out so quickly that the machine arms do not have time to be affected by heat, even when the furnace is working at temperatures as high as 1150° C.

**8. Flexible Shafting.** A selection from a wide range of flexible shafting for a variety of purposes is illustrated and described in a well-produced 16-page booklet. These shafts are made in many diameters, ranging form ⅛ to 1¼ in., and have been successfully used on many machines and in many applications involving otherwise awkward transmission of power, including dental tools, speedometers, revolution counters, motion-picture projectors, scientific instruments, etc.

In addition, the booklet gives descriptions of complete flexible-shaft outfits, and various accessories for use with flexible shafts, including wire brushes, valve-guide cleaners, and rotary files.

**9. Packaged Boiler.** Produced by a world-famous firm of steam engineers, a 4-page leaflet describes and illustrates a packaged boiler, available in a wide range of types and sizes to suit individual requirements, and incorporating many interesting and outstanding features, including rapid and easy installation, full protection against any eventuality, and high overall efficiency at all loads, with no stand-by or banking losses.

The boiler is completely self-contained and extremely compact. No additional auxiliary equipment is required and fully automatic control, involving no attendance, is provided, inasmuch as electronic and electro-mechanical devices ensure safety in operation and provide for the purging of the gas passes before starting up and for total, immediate shutdown in the event of flame failure, low water, or excessive steam pressure.

**10. Drill Bushes for Laminated-Plastic Jigs.** Details and specifications are given in an illustrated 4-page brochure of a range of jig bushes specially developed for use with laminated-plastic jigs made from glass fibre. These bushes are of two types, one of which uses serrations to prevent the bush turning in the jig, while the other employs a hexagon shoulder.

The serrated type can be pressed directly into the jig, or alternatively the glass fibre can be moulded around the bush, the latter being held in position on the prototype component or a plaster former by means of screws or pins. The hexagon type is intended for the latter type of application only.


## MAIL THIS COUPON TO-DAY

THE ENGINEERS' DIGEST, 10.55
120, Wigmore Street, London, W.1.

Date.....

**Please send free and without obligation the literature indicated by the following circled numbers:**

1 2 3 4 5 6 7 8 9 10

Name .....

Position .....

Company .....

Address .....

# THE BLUE PAGES

## A QUICK GLANCE AT THE LATEST TECHNICAL DEVELOPMENTS THROUGHOUT THE WORLD

● *SILICONE-FILLED VALVE TAPPET*

A new, self-contained, self-adjusting valve tappet for use in automobiles and lorries has been developed. This tappet makes use of a silicone liquid of high viscosity in a sealed device, instead of using engine oil for operation. While the exhaust or the intake valve of the engine is being lifted off its seat, a tappet valve carries the load of the push rod. During the lift cycle, the silicone polymer moves from a high-pressure chamber through a leak-down clearance into a low-pressure chamber. After the tappet has reached the closing ramp of the cam and the poppet valve has reseated itself, the tappet return-spring raises the tappet valve, which then creates a recovery passage. The silicone polymer is then returned from the low-pressure chamber through this opening into the high-pressure chamber. The tappet is then ready for the next lift cycle. According to the manufacturers, the amount of tappet leak-down during the valve-lift cycle is comparable with the leak-down of conventional hydraulic tappets. No special camshaft design considerations are said to be necessary, other than the cam ramp design normally used for hydraulic tappets. It is considered that the silicone polymer, with its extremely high viscosity, is the main factor responsible for the excellent operating characteristics obtained with this tappet. The fluid is sealed in the lower half of the tappet by a cup seal, and a tappet return-spring keeps the fluid under pressure at all times. As the fluid is sealed within the tappet, it does not have to be replenished nor does it become contaminated. In the manufacturing process, the silicone fluid is put into the tappet by vacuum filling, and the tappet is sealed under a vacuum of 50 microns in a specially designed filling machine.

● *CHROMIUM CARBIDE FOR HOT-EXTRUSION DIES*

The use of tungsten carbide as a material for drawing-dies has been a well-established practice for many years. In the processing of copper and brass into tubes and rods, the hot-extrusion process plays an important role, and attempts have therefore been made to employ tungsten carbide dies for this process also. However, these attempts have not been successful, because the tungsten carbide oxidizes at the temperatures required for the extrusion of copper and brass. Also, the coefficient of thermal expansion of tungsten carbide is approximately one-half that of steel; this means that at the operating temperature the die insert loses much of its support and breaks under the extrusion pressure. The development of chromium carbides in recent years now, however, provides a material with very good oxidation resistance and hot hardness, making it suitable for hot-extrusion applications. The particular material recommended for this purpose is composed of 83% chromium carbide, 2% tungsten, and 15% nickel. The use of nickel in place of cobalt as a binder metal is accounted for by the fact that chromium carbide is highly soluble in cobalt, so that the latter is not suitable as a binder metal in this case. The chromium carbide compound referred to is highly resistant to oxidation at all temperatures up to 1800° F, and favourable results have been obtained in tests conducted at temperatures over 2000° F. It is recommended that dies made of this material should be preheated in an oven to 1000° F. This reduces themal shock when the die is put into service in the extrusion press. If this is not done, there is a tendency to premature thermal checking on the surface of the nib and a spalling out of the chromium carbide. Also, the die should not be quenched for cleaning or cooling.

● *ACCELERATION OF METAL SURFACE-TREATMENT PROCESSES*

A patent of recent date envisages the acceleration of processes concerned with the surface treatment of metals and alloys. Typical processes of this nature specifically mentioned are carburizing, nitriding, carbo-nitriding, chromizing, and the enrichment of aluminium surfaces with magnesium or cadmium. It is well known that these processes require considerable expenditure of time and relatively high temperatures. The inventors therefore propose to accelerate such a process by activating reaction or diffusion by the processing medium, which may be a gas, a liquid, or a solid in powdered form. Taking the case of nitriding, in which nitrogen enters iron by diffusion, the iron surface is contacted by a boundary layer of reagent gas, from which the nitrogen taken into the iron is obtained. In this case the nitrogen concentration of the gas will increase from the surface of the iron outwards through the boundary layer; the greater the gradient of the nitrogen content across the boundary layer, the higher will be the rate at which the nitrogen enters the iron.

**Meet Ethel Mary Sprott**

It's mid-winter and she's sniffing because she's cold. She's fumbling because her fingers are frozen, she's fed up with the factory because it's like an ice-well. No heaters? Plenty! Trouble is, the building leaks heat like a sieve– especially through the roof! What's the answer? ✳

Factory-warming and fuel-saving in winter, cool-keeping in summer, peace and quiet-making all the year round— that's Fibreglass . . . rot-proof, everlasting, inexpensive. easily-installed Fibreglass insulation.

**Meet Ethel Mary Sprott**

It's mid-summer and she's sweating and swearing because she's hot. She's getting careless because she's drowsy. She's fed up because the factory's like an oven. What's the trouble? No windows or fans? Not on your life! Feel that roof. It's *baking* hot. No wonder production is slacking off. So what? So . . ✳

*wrap her in

**FIBREGLASS** TRADE MARK

FIBREGLASS LIMITED, RAVENHEAD, ST. HELENS, LANCS. (ST. HELENS 4224). FACTORIES AT ST. HELENS, LANCS. AND POSSILPARK, GLASGOW

It is claimed that, by setting up ultrasonic vibrations in the gas, the boundary layer will be compacted, so that the gradient is made extremely high and the reaction time required for processing the piece is correspondingly reduced. This is due to the fact that at ultrasonic frequency the average path covered by an oscillating particle of the gas can be made substantially larger than it would be at the decomposition temperature of the gas. This makes the gas extremely active, the boundary layer is reduced or even possibly destroyed, and the surface of the metal being treated therefore comes into contact with gas of the highest possible nitrogen content. Production of the ultrasonic oscillations can be accomplished by any of the usual methods of generation.

● *CREEP OF NICKEL*

An exhaustive study of the creep characteristics of high-purity nickel has recently been made. The results obtained are of particular interest because of the relatively low temperature at which creep occurs in nickel and because of the widespread use of this metal in jet and other high-temperature engines, heating elements, and other apparatus. This investigation was concerned with the creep of high-purity nickel under constant tensile stress at 300, 700, 900, and 1200° F. The influence of the rate of loading and the effect of strain history on tensile properties at room temperature were also evaluated. As is well known, creep ordinarily takes place in three stages, which follow the initial extension when the load is applied. In the first stage, at 300° F, nickel has a high resistance to creep at all stresses up to 45,500 psi. However, with a further increase in stress of only 500 psi, the secondary creep rate was found to increase by a factor of about 100,000. Strain-ageing was especially prominent at 300° F. While logarithmic plots of creep rate against time were nearly linear in the initial portion of the first stage of creep, non-linear relations were generally obtained between stress and second-stage creep rate. Also, the prior strain history of the nickel had a marked effect upon the second-stage creep rate. The initiation of the third creep stage has been attributed to such factors as the beginning of micro-cracking, increase in creep stress due to a decrease in the area of the specimen, and atomic rearrangement. In all specimens tested at 300, 700, and 900° F, internal disintegration was found to be confined to the region of complete fracture, the fractures being preceded by appreciable necking.

● *HIGH-SPEED THERMOELECTRIC CONVERTER*

In thermoelectric converters of the indirectly heated type an electromotive force is generated in a thermopile winding by heating elements which are not electrically connected to the former. Converters of this type are used for measuring or controlling purposes, and a novel high-speed design recently proposed has been devised to produce an e.m.f. directly proportional to a polyphase load and at the same time to permit continuous adjustment over a wide range of the magnitude of this e.m.f. corresponding to a given load. One of the essential features of indirectly heated thermoelectric converters is that the thermocouples and the means of electrical heating must be arranged to have the greatest possible thermal-transfer relationship, so that heat is rapidly conducted from the heaters to the thermocouple junctions, thereby obtaining a rapid response. At the same time, it is desirable to provide means for conducting away the excess heat and thus to avoid an undue rise in temperature. The inventors of the new device state that thermal converters of conventional design have an extremely long time of response. However, a high speed of response is essential in many automatic control applications. Thermal converters of the conventional type can be designed in which the time of response to reach 90% of the final reading is approximately 15 sec. It is claimed that, in this type of thermal converter, the time of response is shortened to less than one second to reach 90% final reading, while the device is so constructed that heat storage in the heater and in the thermopile elements is greatly reduced.

● *PLASTIC DUCTWORK*

With the increasing use of plastics in shipboard applications, consideration is now being given to the advantages of using plastic, instead of metal, in the fabrication of ductwork. Some of the advantages anticipated are the corrosion resistance in installations where acid or otherwise corrosive fumes are being handled, the saving in weight where corrosion-resistant material is required, and the improved noise-reduction characteristics. In certain cases the non-magnetic properties of plastic ducting may constitute another advantage. Two plastics which appear satisfactory for this application are rigid, unplasticized polyvinyl chloride sheet, which is thermoplastic, and glass-fibre mat or cloth-filled polyester resin, which is thermosetting. Of these two plastics, rigid polyvinyl appears the more promising for extensive ductwork, since the fabrication and installation techniques used with this plastic are similar to those used with metal. On the other hand, glass-fibre reinforced ductwork requires forms, around which the fibrous glass is wrapped before application of the polyester resins. The greatest disadvantage of using polyvinyl sheet is the loss of tensile strength at temperatures above 150° F. Its use in engine rooms or other hot locations may not therefore be practicable. A recently developed method employs inexpensive template paper forms to fabricate ducts of polyester-glass material. A polyester resin containing 3% of grey pigment is used to impregnate the glass cloth. The agents

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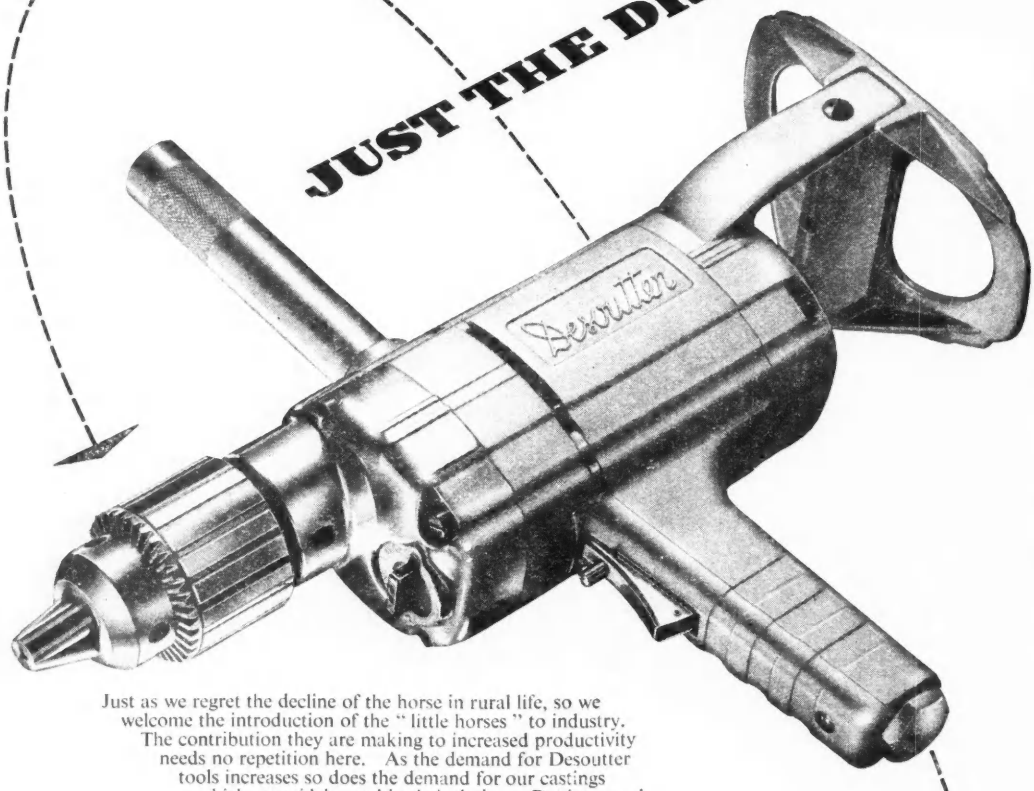


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used to obtain a room cure are cobalt naphthenate and methyl ethyl ketone peroxide. The fabricated section is set aside in a warm place until the resin has cured, after which the edges are trimmed and the form is collapsed and removed. Flanges are made of built-up pieces of glass cloth and resin. Duct sections are cemented together with polyester resin and strips of glass cloth.

### ● *ALLOYS WITH LOW THERMAL EXPANSION*

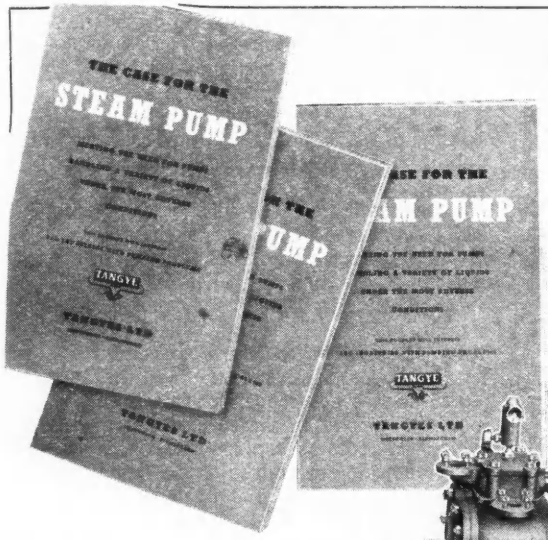
Materials exhibiting extremely low coefficients of thermal expansion are required for use in certain tools and devices such as thermostatic instruments and measuring instruments. Generally, fused quartz, invar, and some ceramics have been used for these purposes, but of these materials only invar is metallic, and even this material is subject to small but significant dimensional changes over long periods. It has now been reported that the thermal expansion of certain cobalt-iron-chromium alloys is extremely low and nearly constant between 65 and 140 F. A cobalt-base alloy with 36·6% iron, 8·9% chromium, and the balance cobalt was found to have a coefficient of thermal expansion of less than $1 \times 10^{-6}$ per C over the above temperature range. The investigators report that the low expansion of such alloys is very sensitive to small variations in chemical composition. Furthermore, some of the alloys undergo a transformation on cooling at low temperatures. The test range covered extended from −310 to +1800 F. Alloys with chromium contents ranging from 8·6 to 9·2% have very low rates of expansion at room temperature. Some of these are reported to have expansion coefficients smaller than those of fused quartz and ordinary invar between −75 and +140 F; however, on cooling to lower temperatures they undergo a first-order transformation of the martensitic type, resulting in a low-temperature phase with a much higher rate of expansion. Temperatures at which these transformations commence are as high as 14 F and decrease with increasing amounts of chromium. The reverse transformation, which produces the high-temperature phase, starts at approximately 1100 F, and is not complete until the alloy is heated above 1600 F.

### ● *EFFECT OF METAL REMOVAL ON STEEL SURFACES*

A recent research paper refers to the fact that the effects of metal removal and heat treatment on and near the surfaces of hardened steel parts are difficult to evaluate, since they cannot generally be completely controlled. For example, it is accepted practice to grind off several thousandths of an inch to remove the decarburized layer on a hardened steel part; however, grinding in itself may introduce additional surface effects. Thus, a finished hardened part may have non-uniform phase or stress distributions near the surface as a result of heat treatment, finishing operations, or both. These non-uniformities may, in turn, have a profound effect on the physical properties of hardened steel parts. A series of hardened plain carbon steels with 5 to 30% retained austenite was studied to determine the utility of metallographic polishing as a metal-removal standard, and the validity of mechanically polished and etched surfaces as being representative of these samples. Reference behaviour was established by the study of samples in which metal was removed electrolytically. It was found that metal removed with a standard metallographic polishing sequence significantly affected the retained austenite content below the final polished and etched surfaces and left large compressive stresses in the surfaces. When using a belt sander for metal removal, the austenite content of the surface increased if the metal was removed rapidly, and decreased with slow removal. In both instances large compressive stresses were left in the surface. After either mechanical metallographical polishing or belt sanding, the compressive stresses could be reduced essentially to zero by removing electrolytically about 0·005 in. from the surface.

### ● *LIQUID-SENSING UNIT*

A new liquid-sensing unit which detects the presence of liquid in 0·4 sec and its absence in 5 sec has been developed and is now employed for a variety of purposes. The complete unit consists of an electrically energized probe containing a thermistor of very small dimensions, a compact power-control package, and an interconnecting cable. For special purposes control units are encased in explosion-proof or vapour-proof housings. Multiple-probe assemblies are built for automation applications in which several chain-operations are required to be automatically performed. Inasmuch as the sensing element has no moving parts, it is not subject to wear, clogging, corrosion, or shock. Moreover, no electrical contact is made with the liquid to be sensed. It is claimed that the unit will operate satisfactorily over a liquid temperature range from −319 to +200 F, and that it can be applied to almost any type of liquid system. It is reported that applications of this unit have so far included its use in fuel systems as a low-level warning indicator or as a high-level cut-off switch in filling operations, for sequencing liquid from one tank to another when predetermined tank levels are reached, and for indicating the presence or absence of liquid. The unit can be made to operate visual or aural alarms, and to control pumps, valves, or motors in response to a change in liquid level. It is further stated that the sensing unit has proved its effective operation in such different liquids as oil, water, liquid oxygen, and petrol. A special type is now being developed for operation in fuming nitric acid.

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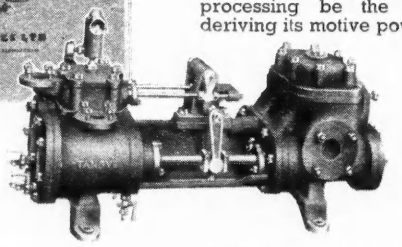

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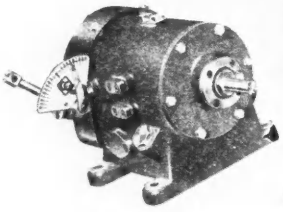

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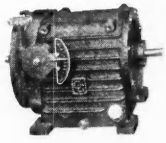

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### ● *PORTABLE PYROMETER*

It is reported that a portable pyrometer, which looks like a microphone on the end of a long pole, has solved the problem of accurately measuring the high temperatures of metals and refractories in cooler ambient air. According to the manufacturers, the instrument will give accurate temperature readings within 0·5%, whereas thermocouples of the type hitherto used for the same purpose have an accuracy not exceeding about 5%. The new surface pyrometer is claimed to be suitable for measuring local temperatures in a range of from 100 to 2400° F, and may be used for the temperature measurement of oxidized steel or cast iron, many oxidized non-ferrous metals, and painted and other surfaces, irrespective of the surface emmisivity. The measuring head of the instrument is mounted on a telescopic arm, which can be extended to a length of 9 ft. It is normally connected by a trailing lead to a portable millivoltmeter, calibrated in degrees of temperature. When used in this manner the instrument is stated to need no external power supply, and readings from the pyrometer are obtained five seconds after the head is placed upon the hot surface. The fact that temperature indications of high accuracy can be obtained with this pyrometer is reported to be due to its unusual design, which produces almost perfect black-body radiation. It is stated that this black-body radiation is found in and between the framework of atoms comprising the heated material, and also holds the key to its exact temperature. When applied to the surface, the concave head of the instrument closes off a portion of the heated surface and forms a uniform temperature enclosure. Black-body radiation trapped within this enclosure is then sampled through a small fluorite window, which is transparent to most of the infra-red spectrum, and measured by a sensitive thermopile.

### ● *PENETRATION OF PROTECTIVE COATINGS INTO RUST LAYERS*

A method of determining the degree of penetration of a fish-oil-based protective coating into rust layers of steel specimens has been developed. Attempts to obtain this information by means of X-ray techniques have not proved successful, and it was therefore decided to prepare a radioactive vehicle of the same composition as the primer to be investigated. Two alternative methods, autoradiography and lapping, appeared applicable to the problem of demonstrating the penetration of the vehicle component into rust layers of steel. Of these the lapping technique was adopted because of the low radioactivity of the fish oil. In this technique the radioactivity of the surface of a painted specimen is determined; a thin layer of the surface is then removed by lapping, and the radioactivity of the newly exposed surface is measured. This procedure is repeated until the protective coating and rust are removed and a bare steel surface remains. The concentration of the radioactive component in layers of the protective coating and rust film at various depths is then determined. Radioactivity measurements of a specimen surface were made with both an end-window Geiger-Müller tube and a gas-flow proportional counter. As the coating and rust layer are removed by lapping, the residual radioactivity and the precision of measurement with the Geiger-Müller tube both decrease. It was therefore found necessary to use the gas-flow proportional counter to verify the presence of the radioactive components in layers close to the bare steel surface, where the radioactivity is relatively low. From the results of the lapping experiments it was concluded that the fish-oil vehicle of the protective coating penetrates the rust layer to the metal surface in measurable quantities. At the metal surface, where no rust was observed, no radioactivity was found.

### ● *IMPROVED RUBBER RINGS FOR HYDRAULIC SERVICE*

In a new moulding process, claimed to increase the strength of O-rings from around 50% of the strength of rubber to some 90%, the improvement is said to be due to the elimination of internal laminations and stresses within the structure of the ring. In this new moulding technique the time lag in filling the die cavity has been made negligible. Thus, none of the material has time to become even partially vulcanized before the die cavity is filled. Moreover, the amount of material introduced into the die cavity is exactly equal to the amount of material required for the part. There is no excess material to produce a flash and cause a pressure increment when the die cavity is filled. Hence, when the pressure on the moulds is released after vulcanization, there is no tendency for the moulded material to readjust its dimensions, and there are no laminated planes within the material, along which stresses can form, even when a slight readjustment is necessary. A multiple die is placed in the moulding machine and brought to the proper temperature. The die is then opened, and a sheet of rubber is slipped between the die halves. As the die closes, each of the die cavities cuts just enough material from the rubber sheet to fill the die. The success of this operation depends on the exact design of the mating edges of each die cavity. When the cavities close, all moulding pressure is absorbed by the die, without transmission of this pressure into the material being moulded. The speed of the new process is claimed to be considerably greater than that of the conventional method. Whereas three different operations were formerly required, the new machine cuts the raw material from sheet stock directly into the die cavity, without the need for removing roughs, and no flash, which must be removed by hand after moulding, is created.

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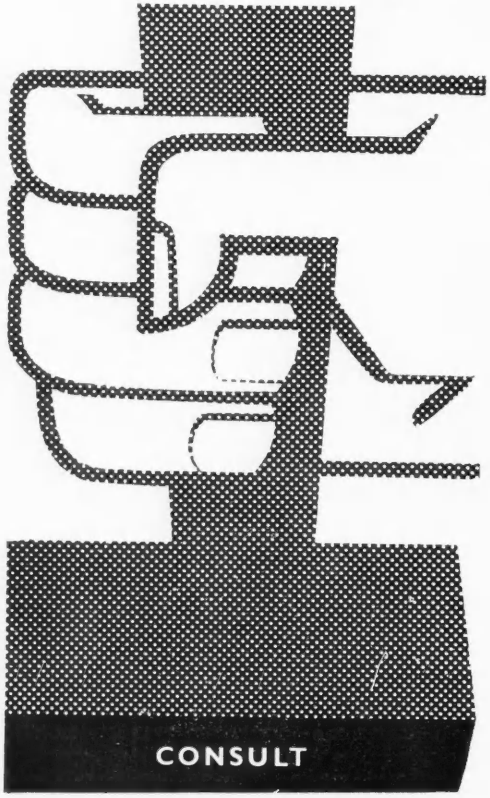


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